THE SUPERCONDUCTING 130 MeV RECYCLOTRON FOR ELECTRONS AT DARMSTADT*

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Abstract

The basic design and the present status of construction of a 130 MeV superconducting cw electron accelerator is described. The accelerator contains 11 multicell accelerating structures fabricated of Nb-metal and is operated at a temperature of 2K. The quality factor $Q \approx 3 \cdot 10^9$ and the average energy gain of each structure is 5 MeV/m. At present the 250 keV injection beam line, the 10 MeV injector, the first beam bend into the main accelerator and the 1st recirculation beamline for injecting the electron beam a second time into the main accelerator are completed. First rf tests of 3 coupled superconducting structures in the injector have been performed. The present status of the whole project as well as the experience from the first test are reported.

I. Introduction

We report here on a 130 MeV superconducting cw electron accelerator presently under construction. This accelerator results from a cooperative effort between the Physics Department of the Universität Gesamthochschule Wuppertal and the Technische Hochschule Darmstadt. This accelerator henceforth called recyclotron for reasons which will become clear below is being installed at the Nuclear Physics Institute at Darmstadt. It will replace the existing [1] low duty factor ($<10^{-3}$) 70 MeV linear accelerator DALINAC which is in operation since 1962 and is still used for single arm high resolution electron scattering experiments. The new accelerator because of its cw beam will allow for coincidence measurements giving a much more detailed insight into nuclear structure as determined from inclusive inelastic electron scattering.

The choice of a superconducting recyclotron and its basic design parameters have been discussed earlier [2], therefore in Sect. II we give only a short summary of the parameters finally chosen, whereas the layout and the present status of the individual components of the accelerator are described in detail. In Sect. III the results of a first test of the injector linac are discussed, while Sect. IV gives an outlook how we intend to proceed in the construction of the accelerator.

II. Present status

The general layout of the 130 MeV accelerator is given in Fig. 1. The various numbers denote the following parts: (1) electron gun, (2) 250 keV electrostatic preacceleration, (3) rf chopper resonator, (4) water cooled chopping orifice, (5) rf prebuncher resonator, (6) superconducting injector linac, (7) superconducting main linac, (8) 1st recirculation for 50 MeV beam and (9) 2nd recirculation for 90 MeV beam.

We have so far partially operated the gun and preaccelerator, the chopper and prebuncher and the superconducting injector linac. In addition to these parts pertaining to the accelerator, a 100 W He refrigerator including a 2 stage compressor and a 4 stage roots pump station have been installed and routinely operated.

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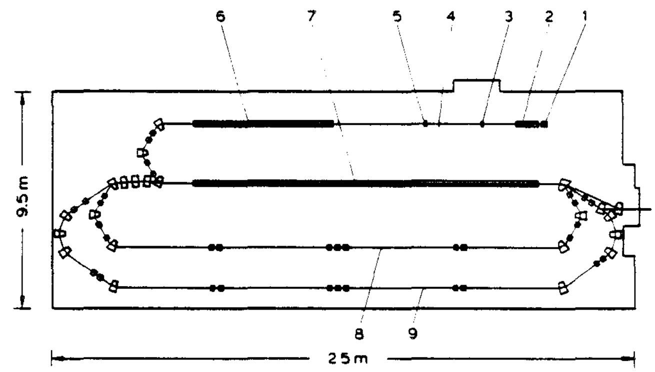

Fig. 1 Schematic layout of the 130 MeV recyclotron

The main design parameters of the accelerator are given in Tab. 1.

Table 1: Main design parameters of the 130 MeV superconducting electron accelerator.

General	Beam energy (MeV)		10 - 130
	Energy spread (kev)		± 13
	cw current (μA)		> 20
Accelerating structure	Type		standing wave
	Mode		π
	Frequency (MHz)		2993.5
	Operating temperature (K)		2
	Quality factor		$3 \cdot 10^9$
	Accelerating field (MV/m)		5
	Power dissipation (W)		4
	Capture section	0.25 m long	1
	Number of structures	1.00 m long	10
Beam transport	Number of dipoles		22
	Number of quadrupoles		34
	rf intensity and position monitors		8

In the following the present status of the various components of the accelerator is given in turn.

Room temperature injection

It covers numbers (1) through (5) in Fig. 1 and consists of the electron gun, an electrostatic preacceleration tube and rf chopper- and prebuncher cavities. Two magnetic lenses, horizontal and vertical steerers as well as three viewscreens, two wirescanners and an rf beam intensity- and position monitor are not indicated in Fig. 1. The electron gun which delivers a DC current of i<2 mA is mounted together with the associated power supplies and control electronics inside a high voltage terminal. Control of filament, beam intensity and two steering coils which had to be incorporated into the gun is achieved via a serial data link, consisting of two 25 m long fibre optics. The preacceleration voltage of

250 kV is generated by a 300 kV/5 mA power supply with a short- and long term stability of $<\pm 10^{-4}$.The acceleration tube is a 34 stage metal-glass construction without O-ring seals.

Chopping of the beam into segments covering 30 degrees of rf phase is accomplished by a cylindrical cavity in which both orthogonal TM_{110}-like modes are excited and which sweeps the beam across a watercooled orifice with a 2 mm bore. A standard prebuncher cavity behind the orifice compresses the 30 degree bunch into 6 degrees at the position where it enters the capture section of the superconducting injection accelerator. All beam handling elements in this 250 keV injection are operated via a computer through a touchpanel and 4 knobs as described below. This system has been in operation since many months and the emittance of the beam has been determined by measuring beam profiles with two wire scanners positioned downstream of the prebuncher cavity. An example for a chopped beam current of 18 μA is shown in Fig.2 together with the results for the horizontal and vertical emittance of 0.4π mm•mrad and 0.2π mm•mrad, respectively, derived from a series of such measurements.

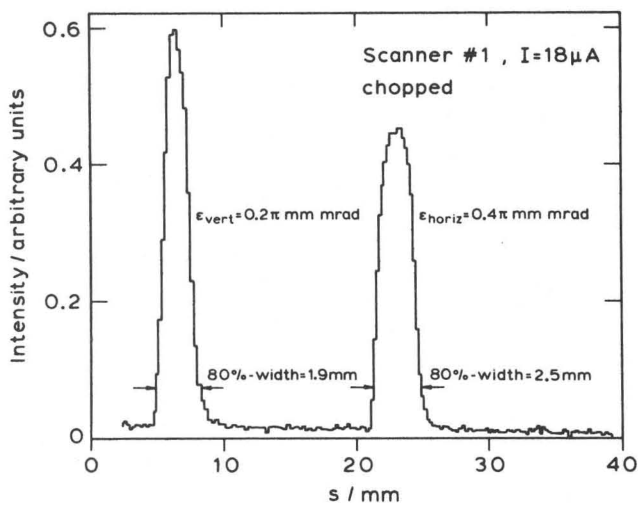

Fig.2 Typical beam profiles measured in the 250 keV injection line with a wire scanner. The coordinate s denotes the travel of the scanner and has to be divided by $\sqrt{2}$ to get the horizontal and vertical motion.

Superconducting accelerating structures

For the 10 MeV injector and the 40 MeV main linac a total of 10 standard accelerating structures (see Tab.1 above) and 1 capture section (which is identical to the standard structures but has only 5 cells instead of 20) are needed. All the structures plus one spare of each type have been fabricated and welded. A set of 2 standard and 1 capture section is at present mounted in the cryostat of the injector linac for a first systems test. Details of the installation are given in Sect.III below.Another such set has been prepared and cold tested at Wuppertal in the meantime.

Cryogenics

The cryostats for the injector and main linac consist of 5 identical modules each 3.4 m long, 1 short module (1.4 m long), 4 end-caps and 1 element connecting the two cryostats. All parts have been delivered and are ready for installation. The present configuration is shown in Fig.3. On the left side the injector cryostat is complete, on the right side just one module is mounted to the connecting element. Connection to the refrigerator is accomplished via a valve box and a 2K transfer line (top left in Fig.3). The refrigerator has been working for several periods of 3-4 weeks each.

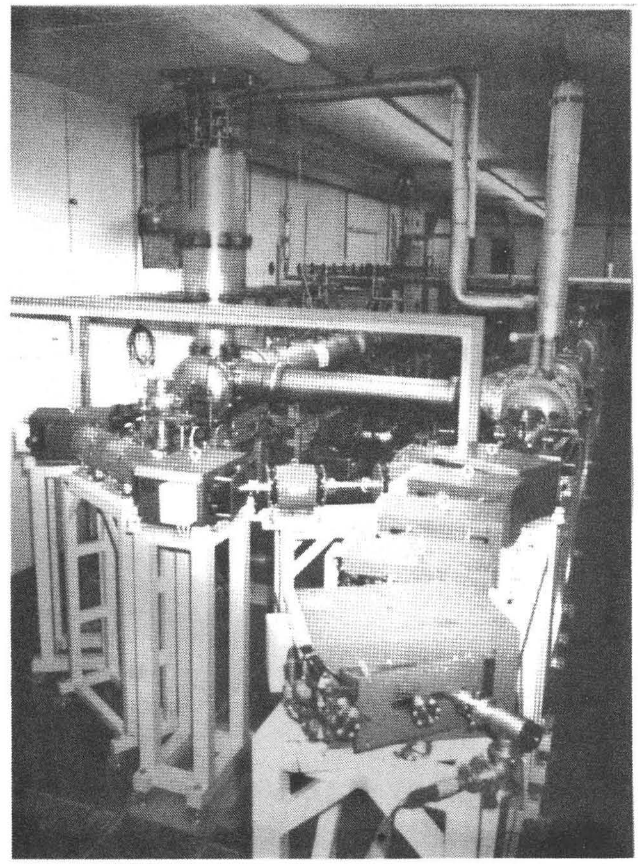

Fig.3 He cryostat with valve box and transfer line, 10 MeV bend and chicane for returning 50 and 90 MeV beams.

Minor deficiencies in two valves (one of them being the inlet valve to the cryostat) prevented a power and final acceptance test up to now.

Beam handling system

The 22 dipoles and 34 quadrupoles for the two recirculations and the 180° bend between injector and main accelerator have been delivered and their magnetic properties were measured. Most of them are installed and aligned. The foreground of Fig.3 shows the isochronous bend for the 10 MeV beam and the chicane for the returning 50 and 90 MeV beams. Figure 4 demonstrates that the installation of the 1st recirculation is completed. At present interwiring of the magnets and installation of the 2nd recirculation is worked on.

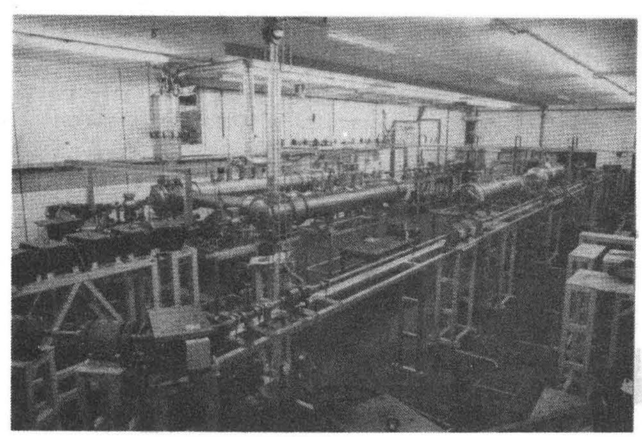

Fig.4 Accelerator cryostats and first recirculation.

rf system

Twelve channels provide the rf power, one for each superconducting structure, and one for the chopper and prebuncher cavities. All power transmitters (each one has a klystron with 500 W output and its associated power supply) are installed. One of the two galleries containing six klystrons, water cooled isolators and output power lines is shown in Fig.5. Low power rf-modules for amplitude and phase control of each channel have been developed and 4 units are finished as well as a PLL circuit to lock the master oscillator to a reference structure.

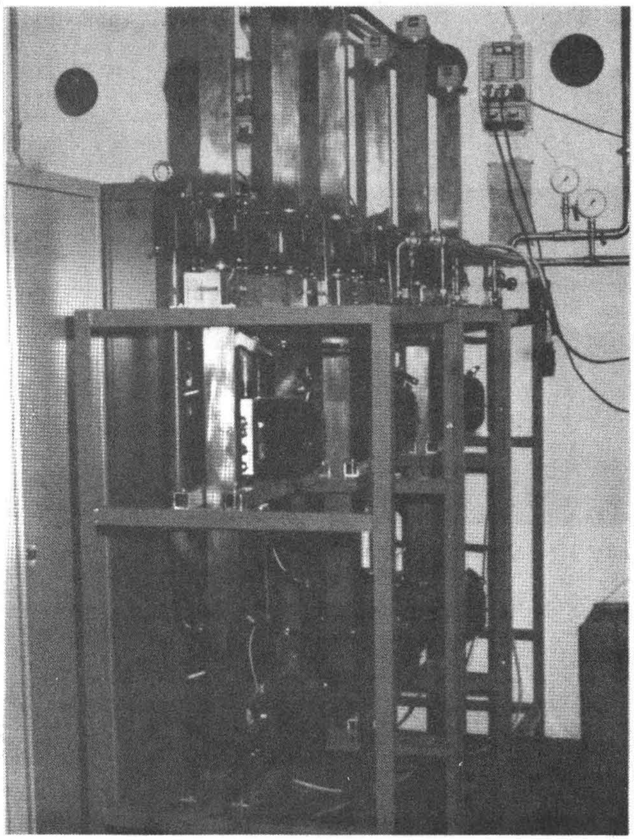

Fig.5 Gallery of 6 klystrons equipped with water cooled isolators standing back to back with their power supplies.

Computer control

The recyclotron will be operated with 2 minicomputers (DEC LSI 11/73) interconnected by DECnet/Ethernet. One system located in the local control area handles all machine control interfaces. All process parameters collected here in a central parameter data base are handled by one process control program. All other utilities necessary for machine control like operator input, status information, parameter display, set up save/restore facilities interface uniquely to this control program. This includes also remote access via local area network necessary for a second LSI 11/73 located in the new control room in another part of the building. Both minicomputer systems running RSX 11 M/M$^+$ have access to the laboratory VAX 11/750 for extended calculations and program development.

The local system is operational, all Ethernet connections are set up, the integration of the remote LSI 11/73 (main control room) into the process control system is under development.

III. First systems test

For this test 2 standard 20-cell structures and one 5-cell capture section were mounted into tuning frames with motor driven gears which allow by stretching the accelerating structure to tune the frequency of the π-mode within a range of 1.2 MHz in case of the 20-cell structures and of 2 MHz for the 5-cell structure. In addition the two 20-cell units were equipped with piezoelectric translators for dynamic fine tuning. Since the structures had been exposed to air for almost six months before their final assembly inside the injector cryostat, as a final treatment they were simply rinsed with demineralized dust free water and dust free methanol. After cooling down it turned out that this had not been sufficient: The unloaded Q which had been between $2\text{-}4\cdot10^9$ before had been deteriorated to $Q_0\approx4\cdot10^8$ for all 3 structures. Also the maximum accelerating field which had been 3.9 and 4.2 MV/m for the 20-cell structures was considerably lowered to values around 1.7 MV/m for all structures. Nevertheless since our most important goal had been the coupled rf operation of all three structures in this first test, little attention was paid to those accelerating fields which can be increased by a proper chemical and heat treatment [3], however, as shown in Fig.12 of Ref. 3 the present low field of the $\beta=1$ capture section prevented an acceleration test.

During the test we observed 3 further mishaps. First 2 of the 3 motordrives failed after a while. Second a shortcircuit developed in one rf output line within the cryostat. Third the tuning range achieved by the piezotranslators turned out to be smaller by a factor of two than specified. Despite these shortcomings which will be fixed for the next test, we were able to operate the 5-cell capture section and the adjacent 1 m-structure coupled in the $4\pi/5$-mode. By doing this we learned that the 5-cell unit is not well suited as a frequency reference due to its pressure dependent frequency gradient of 140 Hz/mbar. This is one order of magnitude larger than the corresponding figure for the 1 m structure. We have further demonstrated that our Phase Locked Loop (PLL) for the frequency reference worked satisfactorily, residual phase deviations amounted to less than 0.2 degrees. The feedback control circuit for the piezotranslators works only for slow changes in the resonant frequency. The same is true for the amplitude and phase control, due to the extreme low pass characteristics of the superconducting structures.

IV. Outlook

During this conference the cryostats will be warmed up and the present 3 accelerating structures will be removed. Three new accelerating structures sitting on the test bench at Wuppertal with fields of 12.3 MV/m (5-cell structure), 7.4 and 3.3 MV/m (20-cell structures) will be equipped with new tuning motor devices, new piezo translators and new input- and output couplers. Furthermore we will incorporate digital low pass filters (without phase shift) into the feedback control circuit for frequency, amplitude and phase control. A second systems test with an anticipated first acceleration test is planned for this summer.

Acknowledgement

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References

[1] H.-D. Gräf, H. Miska, E. Spamer, O. Titze and Th. Walcher, Nucl. Instr. 153 (1978) 9.
[2] H. Heinrichs, U. Klein, G. Müller, H. Piel, D. Proch, W. Weingarten, H. Genz, H.-D. Gräf, T. Grundey, A. Richter, E. Spamer, Lecture Notes in Physics 108 (1979) 176.
[3] T. Grundey, H. Heinrichs, U. Klein, G. Müller, G. Nissen, H. Piel, H. Genz, H.-D. Gräf, M. Janke, A. Richter, M. Schanz, E. Spamer and O. Titze, Nucl. Instr. 224 (1984) 5.