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LATEST RESULTS FROM THE S-BAND SUPERCONDUCTING ACCELERATOR AT DARMSTADT*)

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Abstract In the course of the last two years the 130 MeV superconducting electron accelerator in its different states of construction has produced some 1500 hours of beamtime. Atomic and nuclear physics experiments provided very valuable information about the performance and reliability. Due to an improved field gradient of more than 6 MV/m in one accelerating cavity the injector energy was increased almost up to the design value of 10 MeV and an upper limit for the beam emittance with less than 0.2 π·mm·mrad could be achieved. Investigations for improving the cavity inspection facilities and extensive calculations that predict cavity field profiles and power distributions were made.

I. INTRODUCTION

The superconducting electron accelerator presently under construction at the nuclear physics institute of the Technische Hochschule Darmstadt is designed to produce a cw beam for inelastic electron scattering coincidence experiments. This is reflected in its main parameters listed in Tab. I.

TABLE I Design parameters of the accelerator

Beam energy/MeV		10 - 130
Energy spread /keV		± 13
cw current /μA		≥ 20
Operating frequency / MHz		2997
Number of structures	1.00 m long	10
Capture section	0.25 m long	1

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The superconducting 10 MeV injector produced its first beam in August 87 [1] and status reports [2,3] have been given following the step by step installation of the main linac. Therefore only a brief update of the present status is presented in Sect. II. Main emphasis is laid on the experience with the superconducting cavities and associated equipment like rf couplers and tuners (Sect. III) which we have gained during some 550 hours of machine time for accelerator tests and from 950 hours of beamtime for atomic and nuclear physics experiments (Sect. IV). Finally we give an outlook on developments presently still in progress. The use of the accelerator as a driver for a free electron laser (FEL) has been discussed elsewhere [4-6].

II. STATUS OF INSTALLATION

The photograph of Fig. 1 gives an impression of the present accelerator installation. The electron gun at a potential of - 250 kV (right upper part of the figure) produces a dc beam which is chopped and prebunched in the room temperature part of the

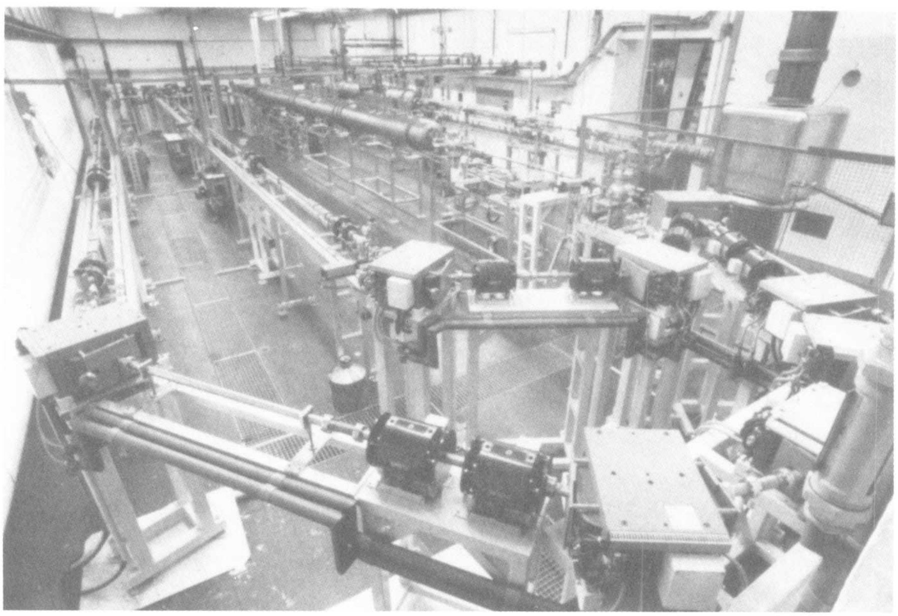

FIGURE 1 View of accelerator from the extraction side

injection (left of the gun). The beam then enters the superconducting injector which consists of a 0.25 m long 5-cell capture section and two standard 1 m long 20-cell accelerating structures. The 10 MeV beam from the injector linac is then bent to the left by an isochronous 180° beam transport system and injected into the main linac (center position) where it gains another 40 MeV. The linac consists of four cryogenic modules with two 20-cell structures each. Three of them are presently installed. Two beam transport systems each consisting of one straight section and two 180° bends allow for recirculation and therefore reinjection of the beam into the main linac. After gaining three times 40 MeV the 130 MeV beam can be finally extracted into the experimental area. Behind the injector two experiments, one for the investigation of channeling radiation and one for nuclear resonance fluorescence studies have been set up.

III. SUPERCONDUCTING ACCELERATING STRUCTURES

The gradients of the cavities summarized in Tab. II have been obtained in two ways by rf measurements following the techniques described in [7] and by measureing the energy gain of the electron beam with a deflection magnet.

TABLE II Fields of superconducting cavities

#	Type	Location	RRR	E_{acc}/(MV/m) (exp)	(rf)
1	5 cell	Injector	100	5.5	5.5
2	20 cell	Injector	30	2.0	2.1
3	20 cell	Injector	100	6.3	7.5
4	20 cell	Linac	30	2.2	—
5	20 cell	Linac	30	0.9	0.9
6	20 cell	Linac	30	4.5	4.9
7	20 cell	Linac	30	2.0	2.7
8	20 cell	Linac	30	1.4	—
9	20 cell	Linac	100	3.4	—

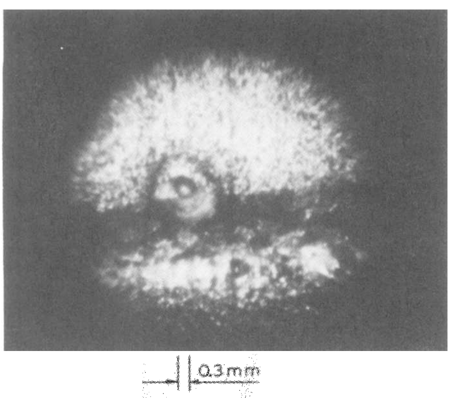

FIGURE 2 Defect near the equator weld inside the 9th cell of a 20-cell cavity

On a first glance the gradients look rather disappointing compared with modern standards but one has to recall the fact that the cavities have been fabricated almost 6 years ago, most of them from reactor grade (RRR ≈ 30) material. The average gradient of these cavities amounts to 2.2 MV/m and is much lower than the corresponding figure for the three samples made from RRR = 100 niobium which amounts to 5.1 MV/m. The third cavity in the injector is the first one of the 20 - cell structures that exceeds the design figure of 5 MeV/m. This has been achieved after an intermediate chemical polishing (≈ 10 μm) of the cavity at the University of Wuppertal.

The reason for an extremely poor performance of a cavity is very probably a "defect" like the one shown in Fig. 2. This "bad spot" is located inside the 9^{th} cell of a 20 - cell structure which has been limited to 1 MV/m. "Defects" of similar appearance have been found occasionally in reactor grade niobium. In the meantime we have ordered six cavities manufactured from high purity (RRR ≈ 280) material to replace the cavities with the lowest gradients presently installed.

IV ACCELERATOR OPERATION

In the course of the last two years the accelerator in its different states of construction has produced some 1500 hours of beamtime for accelerator testing and development but mainly for the two experiments set up behind the injector linac (Tab. III).

TABLE III Beam for experiments

Experiment	Energy / MeV	Current / μA	Time / h
Accelerator Test and Development	1.0 - 9.1	0.1 - 40	550
Nuclear Resonance Fluorescence	2.5 - 8.5	20 - 40	700
Channeling Radiation	3.0 - 7.7	0.001 - 30	250

It has to be noted that the time when the beam was used for atomic and nuclear physics experiments provided very valuable information about the performance and reliability of the accelerator. The nuclear resonance fluorescence experiment required rather high beam currents because of the small cross sections involved. Currents of 20 - 40 μA could be obtained without major difficulties. The beam spot size at the exit window (about 5 m downstream the beamline) was only 4 - 5 mm in diameter and remained that way even for running periods of several days. The channeling radiation experiment [8] requires excellent beam quality because of the small acceptance angle of the crystals used as targets. The beam always met the requirements without any collimation or focusing between the accelerator and the target. By increasing the beam current from several nA up to 30 μA no measurable degradiation of the beam quality could be observed.

During the most recent test period this summer again a leak in the main linac did not allow a phase locked operation of its accelerating structures. Nevertheless some important results could be obtained: i) Due to an improved gradient of the second 20 - cell structure the energy of the injector increased to 9.1 MeV. ii) A 6.8 MeV beam from the injector was injected into the main linac and transmitted through all of its six cavities. Without further acceleration and using three viewscreens, one in front of the main linac, one at its exit (12.2 m downstream) and one in front of the dipole magnet of the extraction (another 3.3 m downstream), to determine the beamsize enabled us to calculate an upper limit of the beam emittance. In horizontal direction we achieved an emittance of $\varepsilon_x = 0.11 \pm 0.03$ π·mm·mrad, in the vertical direction beam spot diameters give a maximum emittance of $\varepsilon_y = 0.21 \pm 0.03$ π·mm·mrad. This number contains some contribution from a small vertical ac deflection of the beam, the origin of which could not be localized yet. iii) The beam was also sent through the first 180° bent of the first recirculation and transported back along the straight section of this beamline. By proper adjustment of the quadrupoles the beam diameter could be kept to within 3 mm at all viewscreens.

V. OUTLOOK

Besides the development of new mechanical coarse tuners and magnetostrictive devices for fine tuning we are presently trying to improve the infrastructure for cavity inspection, treatment and repair. An optical inspection facility has been built. Figure 2 was obtained with this device. When the optical parts of the device are replaced by a string with a bead aligned to the axis of the cavity precise measurements of field profiles can be obtained. Reliable measurements of the π mode do however still present a problem because of its overlap with the 19π/20 mode.

Using the full 20 - cell geometry as input to the URMEL code we have performed extensive calculations to obtain the field profiles and power distributions in the 20 modes of the TM_{010} passband and to study the effect of any single detuned cell in a 20 - cell accelerating structure. The results enable us to calculate field profiles and power distributions for any combination of detuned cells. First calculations with two detuned cells showed good agreement with measurements. The final goal of these studies is to invert the calculations in order to be able to determine the detuning of individual cells from measured field profiles.

With the construction of the accelerator we will proceed as follows: The main linac will be disconnected cryogenically fro the injector because some repair work has to be performed on each of the three modules presently installed. The injector will be cooled down in order to deliver beam to the experiments while the modules of the main linac are worked on and while the fourth module will be equiped with two further structures. During the following test period with all cavities we hope not only to recirculate the beam for the first time but also to extract it to the spectrometer area for electron scattering experiments.

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