FIRST OPERATION OF THE SUPERCONDUCTING 130 MeV CW-ELECTRON-ACCELERATOR AT DARMSTADT*

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Abstract

The installation of the accelerator has been completed in January 1990 and its present status is reported. In the meantime all eleven superconducting structures and the normal conducting chopper and prebuncher resonators are operated by the new microprocessor controlled rf-system which had been tested extensively with the superconducting injection linac in fall 1989. The rf control system is integrated into the main computer control system of the accelerator. Operational experience with a newly developed mechanical coarse and fine tuning system is presented. The horizontal and vertical emittance of the injector beam have been measured systematically. First experience with the transport of the beam through the recirculating beamlines and to one of the spectrometers in the experimental area as well as phase measuresments of the recirculated beam with respect to the injected beam are discussed. Accelerating gradients of the superconducting cavities (including one post purified and three fabricated from 'RRR280' material) determined from beam energies are given.

Introduction and Present Status

Reports on the status of the Superconducting Darmstadt Linear Accelerator (S-DALINAC) have been given regularly. Therefore, we will focus on the progress which has been achieved since the most recent reports [1,2] in late summer last year. The design parameters of the S-DALINAC are summarized in Tab.I below.

TABLE I
Design parameters of the S-DALINAC

Beam Energy / MeV	10 – 130
Energy Spread / keV	± 13
CW Current $/ \mu A$	≥ 20
Operating Frequency / MHz	2997
Number of Structures (1 m)	10
Capture Section (0.25 m)	1

Most of the figures quoted above like energy, energy spread, and cw operation are requirements resulting from the fact, that the accelerator (besides being a driver for an FEL) will be used for inelastic electron scattering coincidence experiments.

The installation of the accelerator could be completed in January of this year. This is documented by Fig.1, a photograph of the accelerator taken from the side where the beam is extracted to the experimental area. In the upper right part the 270 keV injector can be seen, followed by the superconducting injector linac formed by a short cryomodule, housing the 5-cell capture section, and a standard cryomodule containing two 20-cell accelerating cavities. An isochronous beam transport system (180° bend) allows the beam from the injector to enter the main linac (center of Fig.1) which consists of four cryomodules, containing two 20-cell cavities each. The foreground of the photograph shows the two 180° bends of the recirculating beamlines. Their straight sections (left portion of Fig.1) lead to two identical bends (in the rear of the photograph), where the recirculated beams are reinjected into the main linac via a four magnet chicane. Extraction of the beam to the experimental area is performed in the lower right corner of Fig.1. The magnets sitting to the right of the straight section of the first recirculation form the beam handling system of the FEL project [3]. They will be installed during the next shutdown this summer.

Performance of the Superconducting Cavities

The present installation contains quite different cavities made from niobium of different purity ranging from RRR = 30 to RRR = 280. The average accelerating field of the RRR = 30 cavities (four 20-cell cavities) amounts to 2.7 MV/m, whereas the RRR = 100 cavities (two 20-cell cavities and the 5-cell capture section) yield 5 MV/m. The prototype of a series of six 20-cell cavities fabricated from RRR = 280 niobium achieved an accelerating gradient of 6.6 MV/m but showed a severe degradation in Q_0 after an intermediate warm up to 130 K due to a shutdown of the refrigerator. Since simil-iar effects have been observed also in other laboratories [4] with cavities made from high RRR niobium the next two cavities of this series were fired at 650°C for several hours in the UHV furnace at Wuppertal prior to installation in the accelerator cryostat. Both cavities reached 5 MV/m with $Q_0 = 1 \cdot 10^9$ and were limited at 6 MV/m with $Q_0 \approx 5 \cdot 10^8$ and their performance was not affected by a temperature cycle from 2 K to 180 K and back to 2 K. The present installation also contains a 20-cell cavity originally made from RRR = 30 material which has been postpurified by high temperature titanium treatment [5] at the University at Wuppertal. This cavity achieved a gradient of 3.6 MV/m quite well in agreement with a value of 3.9 MV/m determined in a first test at Wuppertal. We therefore presently conclude that there are two possible ways to achieve the design gradient of 5 MV/m with our 3 GHz 20-cell cavities: i) postpurification by high temperature titanium treatment from the outside [5,6] which does not require a subsequent chemical polishing from the inside and ii) fabrication of cavities from high RRR niobium which apparently requires a heat

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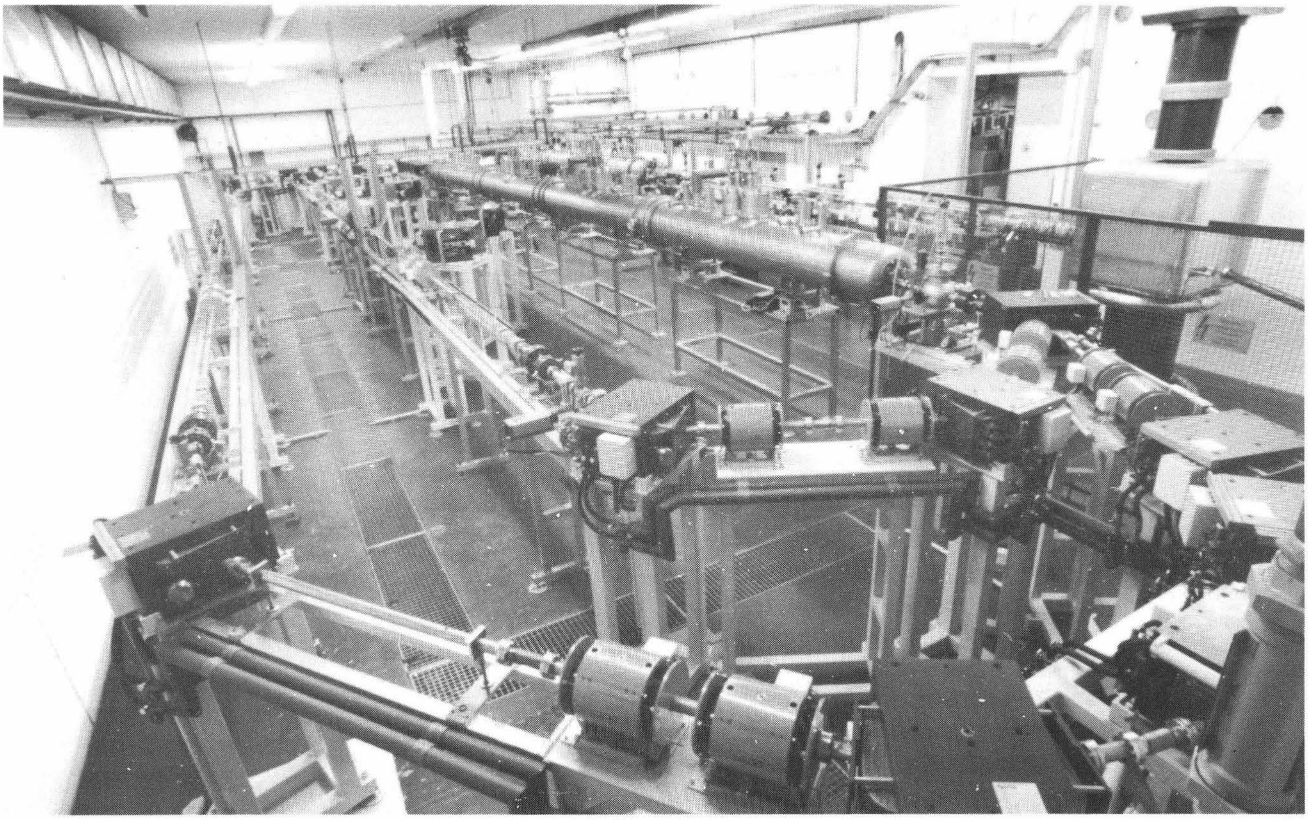

Fig.1 Photograph of the Darmstadt superconducting 130 MeV cw-electron-accelerator

treatment (very likely for outgassing of hydrogen) prior to the installation of the cavities.

Developments

Besides the properties of the cavities themselves the performance of the equipment directly associated with the cavities inside the cryostat is extremely important. We therefore developed a new mechanical coarse and fine tuner described in detail in Ref.[1].

In the present installation, the 5-cell capture section and three new 20-cell cavities are equipped with these tuners. Two of them operated extremely well since January whereas the other two got stuck because of too close tolerances in the series production.

Similiar considerations like in the case of the mechanical tuners led to the development of new rf input- and output couplers. The new design basically consists of a concentric tube inside the cutoff tube of the cavity, forming a coaxial line with an impedance of 21 Ohms, which is shorted at the end pointing away from the cavity. The 50 Ohms 7/8" coaxial input line is connected radially to this device via a $\lambda/4$ impedance transformer at a distance of $\lambda/4$ from the shorted end. Calculations using the computer code URMEL [7] predict that an external Q of $3 \cdot 10^7$ will be obtained with the distance between the open end of the center tube and the iris of the first cell of the cavity being as comfortable as 80 mm. The cylindrically symmetric construction ensures that the electron beam sees no transverse electrical field at all while entering or leaving the cavity. The coupler is mechanically very rigid, promising a good reproducibility of the external Q. Two prototypes have been built and are presently investigated at room temperature. Next steps will be the calculation of the coupling to cavity modes other than the fundamental TM_{010} passband and measurements using a variable coupling between the 7/8" input line and the coaxial line of the coupler.

In connection with the fabrication of the six new cavities a new method for the tuning of the field flatness has been developed. Following the ideas of ref.[8], a comparison was made between the Eigenfrequencies of the fundamental passband calculated with URMEL and via a lumped circuit model. The analysis shows, that in our cavities, which have a cell to cell coupling of 4.2%, coupling to the cells following the direct neigbours still amounts to $7 \cdot 10^{-4}$, decreasing by approximately a factor of 50 from cell to cell when looking at even more distant cells. We therefore developed a tuning method, which works as follows: In a first step the field profile of the π-mode is determined by a bead pull measurement. Then the most evident deviations from the ideal field profile are tuned to such an extent, that the phase of each cell can be expected to be correct. In a second step the frequencies and field profiles of all 20 modes of the fundamental passband are measured and from these data the complete matrix describing the Eigenvalue problem is calculated. This means, that coupling from each cell to any other cell is taken into account. Then in a numerical procedure the Eigenfrequencies of the individual cells are varied in such a way, that i) the desired frequency for the π-mode and ii) a flat field profile for the π-mode are achieved. The results of this calculation are the necessary corrections for the Eigenfrequency of each cell and mode frequencies as well as field profiles for each step of the correction procedure. This allows a quick check during the final tuning procedure by measuring the mode frequencies any time a cell has been tuned. The result of this procedure is a fieldflatness of $\leq 2\%$ in the π-mode.

Accelerator Tests and Utilization of Beam

In order to operate the eleven superconducting cavities of the completely installed S-DALINAC, the new microprocessor controlled rf system [9] had to be put into operation in January of this year and has been working without major problems since then.

In order to recirculate the beam from the main linac and to accelerate it correctly two requirements have to be observed: i) the energy of the recirculated beam has to be five times the energy of the injector beam because the last magnet of the chicane for reinjection is identical with the last magnet of the 180° bend for the beam from the injector and ii) the phase of the recirculated beam has to match the phase of the beam from the injector. The energies of the injector beam as well as of the recirculated beam are easily determined from settings of the dipole magnets in the respective bends whereas for the measurement of the relative phases rf current monitors in front of and behind the main linac in conjunction with a pulsed beam are used. Beam pulses with a width of 70 ns (the round trip time in the first recirculation amounts to 135 ns) at a repetition rate of 1 kHz allow to distinguish between signals in the rf monitors induced by the injector beam or the recirculated beam respectively.

A phase lag of 10° of the 20 MeV recirculated beam with respect to the injector beam could be measured at the position of the rf monitor in front of the main linac. Taking into account the not yet completely relativistic beam energies, this means, that the path length of the first recirculation has to be increased by 2 cm. We will during the next period of operation continue these measurements and investigate to which extent the chicane will tolerate a deviation from the energy ratio of five to one.

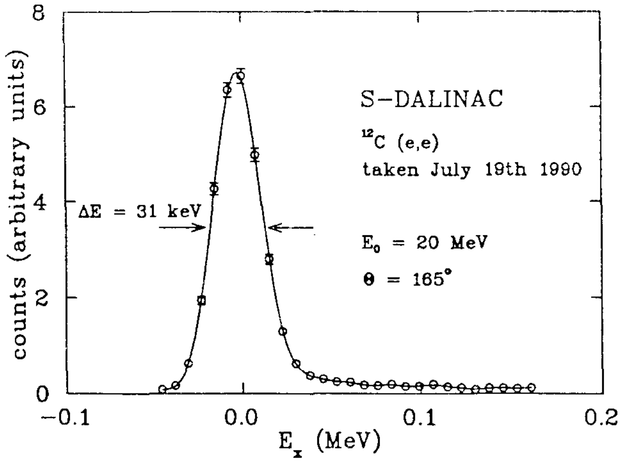

Fig.2 First spectrum of elastically scattered electrons obtained with a 20 MeV singles pass beam

Finally a 20 MeV single pass beam was extracted from the accelerator and reinjected into the existing beam transport system [10] to the 169° high resolution spectrometer. Figure 2 shows a first spectrum of elastically scattered electrons obtained there with the cw beam from the new S-DALINAC.

The properties of the injector beam were measured extensively at beam energies between 4 and 6.5 MeV and their dependence on the focussing of the 270 keV beam from the room temperature injection into the superconducting capture section was studied. It turned out, that the normalized emittance is always between 1 and 3 π mm mrad in the horizontal as well as in the vertical direction; no significant dependence on the beam energy was found. Best results were always obtained, when the 270 keV beam was focussed in such a way, that it had a waist at the entrance of the 5-cell capture section.

We also found that the orientation of the phase space ellipses do not agree with the predictions of simulation calculations. An additional quadrupole doublet behind the injector linac is therefore used to optimize the beam transport through the isochronous 180° bend, which by itself is not very tolerant with respect to different orientations of the phase space ellipses.

Outlook

Presently the accelerator is at room temperature and another two RRR = 280 cavities are being installed. At the same time the 5-cell capture section will be replaced by a cavity which is able to operate at higher gradients and the three inoperative tuners of the old version will be replaced by new ones.

The magnets of the beam transport system for the FEL have to be incorporated into the straight section of the first recirculation, because the delivery of the undulator is scheduled for December 1990. Also the modification of the room temperature part of the injection (installation of a high intensity gun and a subharmonic chopper- and prebuncher system) has to be performed during this shutdown period. We expect the accelerator to be operative again by the end of October.

Acknowledgement

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