EXPERIENCES WITH TESLA CAVITIES IN CW-OPERATION AT ELBE

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Abstract

The radiation source ELBE is based on a 40 MeV, 1mA linear accelerator. Each of the two accelerator modules contains two original TESLA cavities. Cryostat and RF supply are optimized for the requirements of cw-operation. ELBE is in routine user operation for more than 3 years and many measurements and operational experiences will be presented. Maximum field strength and beam current in cw-operation which were reached in practice are discussed. By pulsing of the RF higher acceleration fields have been reached. In addition a processing effect was observed in the pulsed mode which leads to significant reduction of the field emission. Unwanted temperature effects at HOM couplers caused by insufficient cooling and their effects on the beam energy and stability will be shown. It is also discussed whether the original TESLA cavities are an optimal solution for the energy and beam current at ELBE.

INTRODUCTION

At Forschungszentrum Dresden-Rossendorf a superconducting Electron Linac with high Brilliance and low Emittance (ELBE) has been constructed which can deliver a 1 mA continuous wave (cw) beam at 40 MeV [1]. The electron beam is used to generate infrared light (Free Electron Lasers), X-rays (electron channelling), MeV Bremsstrahlung, fast neutrons and positrons. For the production of high secondary radiation fluxes high average electron beam current is necessary. Therefore superconducting accelerator technology must be applied. An own development of cavities which are optimized for high average beam currents was too expensive. Therefore the available TESLA cavities [2] were used. Because cw operation was not planned in the TESLA project those cavities were not designed for high average beam currents. Therefore there is a general question about the suitability of this technology for applications e.g. at ELBE.

ELBE CW LINAC MODULE

The ELBE linac module using the mentioned TESLA cavities was developed together with the HEPL Institut of the Stanford University, see Fig. 1. Substantial differences to the cryostat designed for pulsed operation at DESY are the He phase separator for high helium consumption (up to 10 g/s) and the RF coupler system for

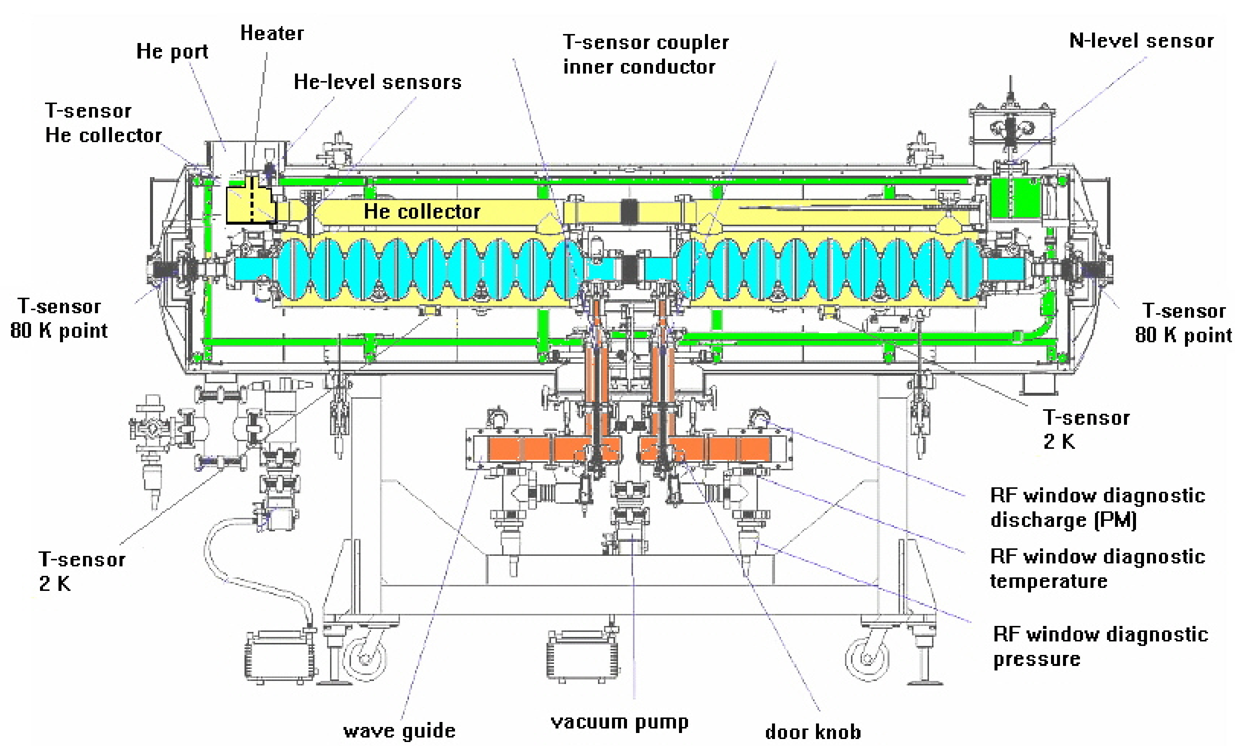

Figure 1: The ELBE linac module for cw operation

high average RF power of approximately 10 KW per cavity. The ELBE modules work very reliably in user operation since 2003. At present more than 3500 hours per year are delivered for routine user operation .

RESULTS

Unloaded Q-Value

Unloaded Q was measured after fabrication of the cavities at the vertical test stand at DESY in 2000. Fig 2 (a) shows the achieved acceleration field of all four cavities (C1- C4) at 1,8 K. After housing the cavities in the helium tank by welding and 4 years of operation a reduced field for all cavities was observed. Fig. 2 (b) shows the field gradient of the same cavities 2006 at 2 K. The difference in Q in the plateau region is caused by the different cavity temperature and well understood. It was assumed that the essential degradation of the gradient is caused by contamination during the welding process and due to insufficient vacuum conditions during maintenance work at the cryomodule. In consequence the originally designed maximum ELBE energy of 40 MeV was not achieved and amounts to 35 MeV at present.

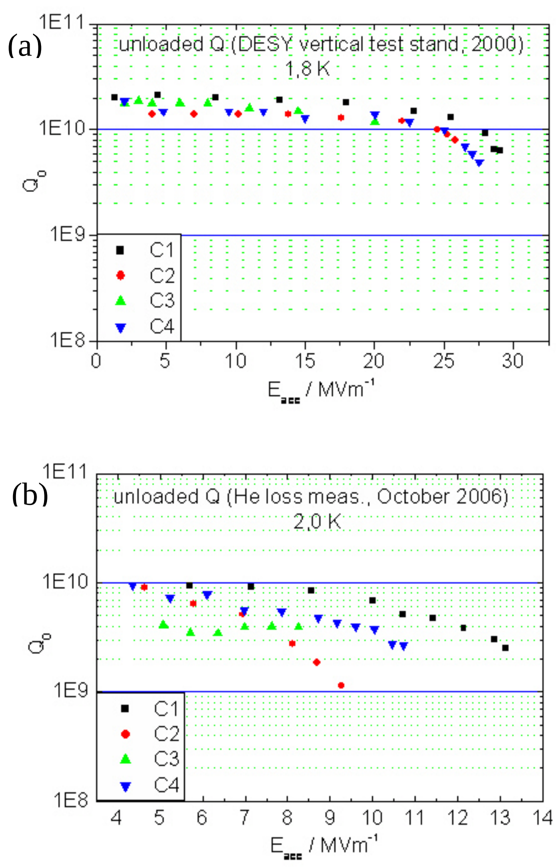

Figure 2: Acceleration gradient of the ELBE cavities after fabrication (a) and after He-Tank welding and four years operation (b)

Field emission

Investigations of the limitation of the maximum acceleration fields at the ELBE cavities show that it is mainly caused by field emission. The situation was essentially improved by applying RF pulses which can be done up to 14 MV/m during the short (8 ms) RF pulse. We found that a stepwise increase of the field gradient from 10 to 14 MV/m over 5-7 hours can reduce the field emission level as shown in Fig. 3. This kind of processing was observed to be stable over several months.

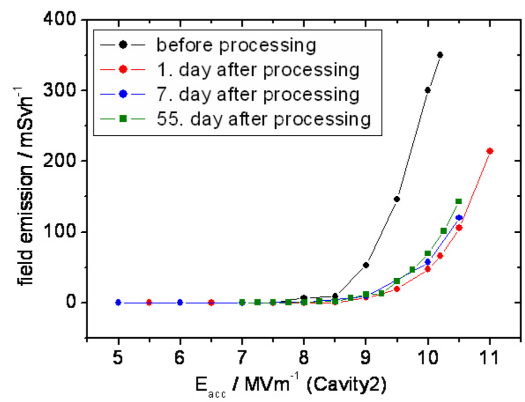

Figure 3: Stable reduction of field emission level by pulsed RF processing

Microphonics

Phase fluctuation due to microphonics excitation was measured using the phase controller signal at operation. Fig. 4 shows the measured phase distribution width (rms) versus the acceleration gradient. Phase jitter blows up dramatically at gradients higher than 9 MV/m due to the excursive rise of helium flow. The real phase jitter in the cavities can be calculated from the data in Fig. 4 by divid-

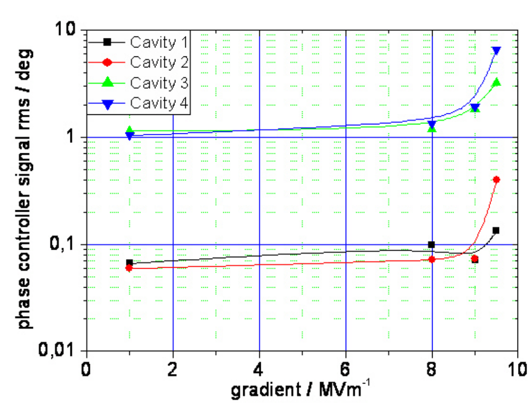

Fig 4: Rms of the phase controller signal distribution versus acceleration gradient for all ELBE cavities

ing by the control loop factor which amounts to 70 in our case. The average level of phase jitter due to microphonics excitation is lower than 0,1 degree for acceleration gradients lower than 9 MV/m. The big difference between the two acceleration modules is not understood at present.

Energy stability

During ELBE routine operation it turns out that the beam energy after switching on of the RF drifts up to higher energy values. During the first four hours the beam energy at 20 MeV rises by about 1 MeV. Investigation of the single contributions of each cavity to this drift shows similar behaviour of both cavities as shown in Fig 5. Several studies were carried out to understand the mechanism. It can be outlined as followed:

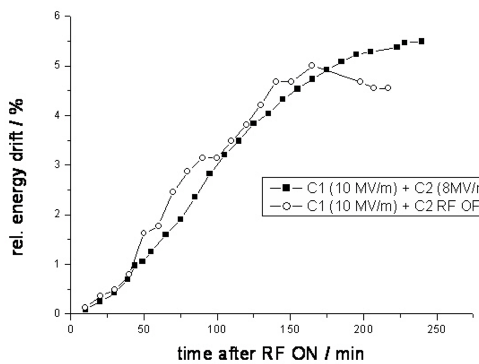

Figure 5: Drift of beam energy during the first hours after switch on of RF in ELBE linac module one. The energy drift during operation with two cavities (full quads) and with only cavity 1 (open circles) were measured.

- forward and return RF power as well as field emission dose rate drift with the time constant like beam energy which excludes any change in RF matching. The same drift behaviour is observed without electron beam. Hence drifts in injector or linac RF phases can be excluded.
- The signal at the pickup antenna was measured to be constant during the drift period. This fact excludes the RF control system as a potential cause.
- No significant temperature change is observed on pickup antenna.
- Dramatic temperature rise up to 50 K is observed on both HOM coupler bodies. However the time to temperature saturation is quite shorter (20 min) than the energy drift time after switching on of RF power. The HOM temperatures on both sides without RF power were measured to be more than 10 K which is above the critical niobium temperature.

We conclude from these observations that a temperature rise in the vicinity of the HOM coupler could be the reason for the energy drift. A time dependent interface between normal and superconducting state can affect the electric field at the pickup antenna mounted close to the HOM damper. The decreased field at the antenna would be compensated by the RF control system in this scenario. In consequence the in-coupled RF power and also the beam energy rise. The normal conducting HOM damper can be heated up further by heat load from the 1.3 GHz fundamental wave which is the most intensive mode. We conclude that the cooling of HOM damper bodies is insufficient in our set up. In practise we avoid energy drift at ELBE by using an active control loop system. It is based on energy measurement with stripline beam position monitors in dispersive beam line sections and compensation of the described drift effect by tracking the acceleration field in one of the four ELBE cavities.

HOM damping

The total power of damped HOM modes was measured in one of the ELBE Tesla cavities in three different frequency ranges (1.7-2.2 GHz, 2.2-2.5 GHz, 2.5-3 GHz). Additional dipole modes were separated from monopole modes by injecting the electron beam on and off the cavity axis. Only in the lowermost frequency range an essential contribution of dipole modes to the total damped power was observed, as shown is Fig. 6. The total power which is damped in the HOM couplers at typical ELBE energies and beam currents is less than 500 mW. The contribution of dipole modes which can potentially destroy the beam quality is less than 100 mW. We conclude that for ELBE beam conditions no HOM dampers are necessary at all.

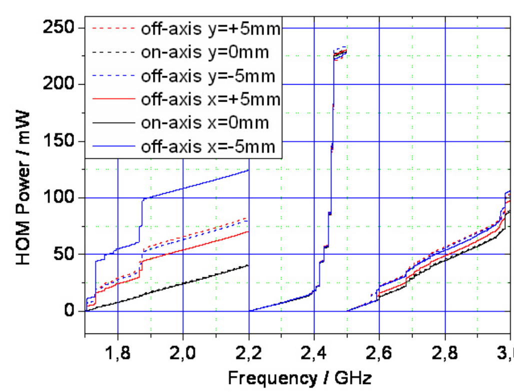

Figure 6: Total damped power of HOM at typical ELBE beam parmeters (20 MeV, 240 µA)

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[1] F.Gabriel et al. NIM B 161-163 (2000), 1143-1147

[2] TESLA Test Facility Linac- Design Report (Ed. D.A. Edwards), DESY print TESLA 95-01