A PULSED-RF HIGH-POWER PROCESSING EFFECT OF SUPERCONDUCTING NIOBIUM CAVITIES OBSERVED AT THE ELBE LINEAR ACCELERATOR

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Abstract

The driver LINAC of the ELBE radiation source is built for CW operation. However, in some cases a pulsed-mode operation was desired to extend the otherwise stringent gradient limits. The main restriction results from field emission that decreases the Q of the cavities which was evaluated from measurements of the liquid helium consumption. After pulsed-mode operation with gradients exceeding the maximum CW accelerating gradients by 30–40% a significant reduction in the field emission was observed. This in turn allows higher accelerating gradients to be used in CW as well. We attribute this behaviour to an RF-processing of the cavity surface which burns off field emitters.

INTRODUCTION

The ELBE accelerator utilizes two cryomodules each containing two 9-cell TESLA cavities. Though the design and production tests show that at least a 15 MV/m accelerating gradient should be reached we were never able to drive any of our cavities much beyond 10 MV/m. This limit is given by the onset of field emission which leads to an excessive heat load and instability introduced into the helium supply system.

HEAT LOAD MEASUREMENTS

The helium supply system of the ELBE cryostats is designed to minimize pressure fluctuations in the helium vessel. This is necessary because the helium pressure influences the tuning of the accelerator cavities. Any fluctuations lead to changes in the resonance frequency of the cavities. The low-level RF system cannot fully compensate for the resulting phase jitter of the accelerating field which leads to energy fluctuations of the accelerated beam.

A constant pressure can best be realized with a constant gas flow. Therefore, we keep the fill valve which determines the flow of liquid helium into the cryostat at a constant setting slightly above the expected consumption. The extra helium fed into the cryostat is evaporated by a heater which is controlled to keep the helium level constant. Rapid changes of the set accelerating gradient are compensated with a feed-forward control acting on the heater.

This control scheme now easily allows a readout of the heat load introduced from the RF field. It is is just the difference between the heater power with the accelerator cavity at gradient or off. The feed-forward control can be switched off for that purpose. This type of measurement of the helium consumption is stable and reproducible as the whole liquefier remains at a steady operation point and only the load is distributed between the heater and the RF losses.

CAVITY BEHAVIOUR IN CW OPERATION

In addition to the heat load measured by the helium consumption we measure the radiation dose rate generated by the accelerator cavities. Typically, we use the room monitor for this measurement. Therefore, in most cases the dose rate cannot be quantitativly compared between different accelerator modules due to the differing geometry. For any single cavity it is, however, reproducible and yields significant insight in the origin of the RF losses.

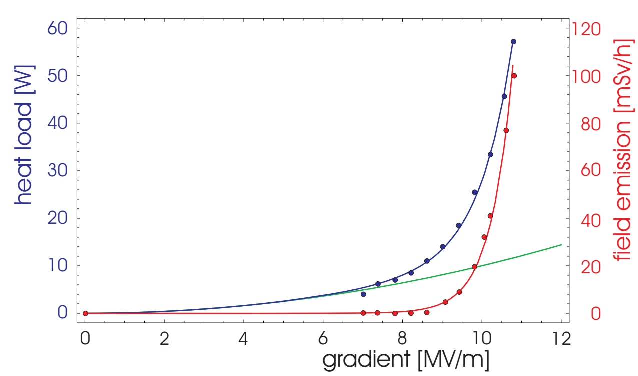

Figure 1: Typical data for heat load and field emission generated by our cavities in CW operation. The green line shows the ohmic RF losses, the blue line is a fitted qudratic-plus-exponential model. The field emission is well fitted by a single exponential.

One typical measurement is shown in Fig. 1. From the residual resistance of the superconducting niobium cavities results a heat load that depends quadratically on the accelerating gradient. But this relation holds for low gradients, only. At a certain level of the accelerating gradient we observe the onset of field emission, seen both in the radiation dose rate as in the helium consumption. The heat load and the instability of the field emission limit the gradients that can be used in CW operation to 10 MV/m, typically.

PULSED-RF OPERATION

To overcome the otherwise stringent gradient limit for special experiments we have tried to operate our accelerator modules with pulsed RF. One example is shown in Fig. 2 below. The RF feed is switched on with a fixed forward power approximately 12 ms before the actual beam pulse starts. Depending on the cavity tuning it takes a few miliseconds until the gradient reaches the preset value. At this time the control loop kicks in and stabilizes the RF field at the desired amplitude and phase. For a detailed description see [1].

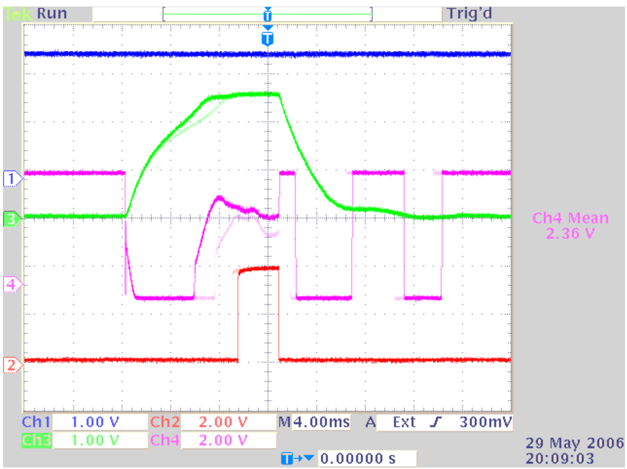

Figure 2: Pulsed-RF operation of an accelerator cavity. The green trace shows the gradient, the red one is the loop-lock signal and the pink trace shows the signal of the phase control loop.

With this mode of operation we were able to drive our cavities up to 15 MV/m. The gradient is mainly limited by the Lorentz force detuning. The mechanical tuner is set to be within the resonance bandwidth at the final gradient which is required for the control loop to work properly. However, the cavities are far-off detuned at the beginning of the RF pulse, so, the coupling of the feed RF to the cavities is very weak and the field amplitude rises only slowly.

A first beam test of this pulsed-mode operation was run in May, 2006. In this test the first accelerator module was still operated in CW. Both cavities of the second module were, however, operated in pulsed mode. It showed that both cavities would stabily hold 15 MV/m with the field emission an helium consumption reduced by the duty cycle. The beam quality did not show any degradations with respect to the CW operation that would indicate a reduced stability of this operating mode.

RF-PROCESSING EFFECTS

During the tests with the pulsed-RF system a reduction of the radiation dose rate around the cryomodules was observed. We attribute this behaviour to an RF-processing of the cavity surface which burns off field emitters. This observation is in contrast to previous tests which did not show major training effects for cavities operated for several hours at the maximum gradient they would hold in CW operation.

To verify this observation both cavities of the first ELBE cryomodule were trained with pulsed high gradients up to 15 MV/m. This gradient is about 40% above the maximum that could be reached in CW operation. The result was a significant reduction in field emission as shown in Fig. 3. This now allows an operation of both cavities at gradients that are about 2 MV/m higher than previously reached with the same heat load (see Fig. 4) and stability. Later tests showed a slight degradation of the effect with the major part of the gradient increase still usable.

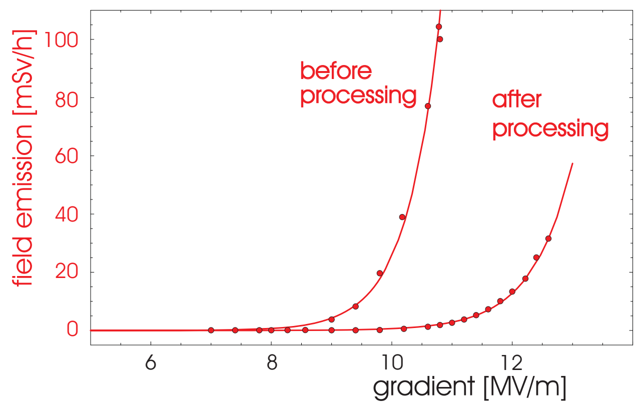

Figure 3: After a high-gradient pulsed-RF training run the onset of field emission occurs at much higher gradients.

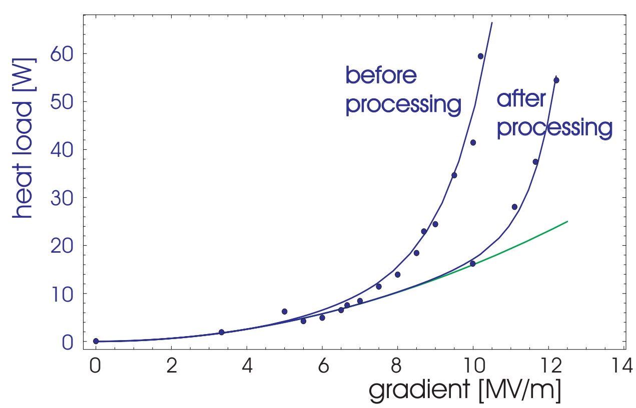

Figure 4: After a trining run with pulsed RF the helium consumption is considerably reduced in CW operation as well.

REFERENCES

[1] A. Büchner, EPAC'06, Edinburgh, June 2006, MOPCH151.