1ST RF-MEASUREMENTS @ 3.5-CELL SRF-PHOTO-GUN CAVITY IN ROSSENDORF

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Abstract

At the Forschungszentrum Rossendorf the development and the setup of the 2nd superconducting radio frequency photo electron injector (SRF-Photo-Gun) is nearly completed. In this report we present the results of the cavity treatment. The warm tuning was carried out considering pre-stressing and the tuning range of both tuners (half cell and full cells). The optimal antenna length of the main coupler and both fundamental pickups were determined by practical external Q studies. Furthermore the characteristic tuning curves of the choke filter and both HOM filters were simulated, measured and tuned at the pi-mode frequency. The preparation (etching and rinsing) and the vertical cold test were done at DESY.

INTRODUCTION

For future FEL light sources and high energy linear accelerators a high current electron gun with high brilliance is absolutely essential. Thus, an innovative superconducting RF photo injector (SRF gun) is under development at the Forschungszentrum Rossendorf (ELBE), which is a collaboration of BESSY, DESY, MBI and FZR and supported by the European Community.

Table 1: rf cavity parameters calculated with MWS© normalized to 50MV/m peak axis field

stored energy U	***32.5 J***
quality factor Q_0	***$1x10^{10}$***
dissipated power P_c	***25.8 W***
geometry factor G	***241.9 Ω***
acceleration voltage V_{acc} acceleration gradient E_{acc}	***9.4 MV*** ***18.8 MV/m***
shunt impedance $R_a = V_{acc}^2 / 2P_c$	***$1.72x10^{12}$ Ω***
R_a/Q_0	***166.6 Ω***
E_{peak}/E_{acc}	***2.66***
B_{peak}/E_{acc}	***6.1 mT/(MV/m)***

This gun allows continuous wave operation at an energy of 9.4 MeV and an average current of 1 mA. It can generate short pulses and high-brightness electron beams, as known from the conventional photo-injectors. Moreover, the use of the superconducting cavity allows cw-mode operation and thus high average currents. Table 1 shows some simulated rf cavity parameters.

The current progress of this project is presented in [1]. This paper deals with the treatment of the cavity itself, one of the main parts of the SRF-Gun. Fig. 1 shows a schematic of its design which is described more in detail in [2].

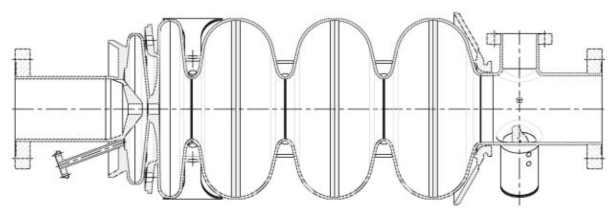

Fig. 1: cross section of the cavity design.

CAVITY WARM TUNING

In order to get the right field distribution and the accurate frequency at operation inside the cryostat, one has to consider different tuning parameters.

Table 2: evaluation of the estimated frequency @ 300K

operating frequency @ 2K	***1300.0 MHz***
cool down shrinking (measured @ ELBE)	*- 1.97 MHz*
50µm BCP @ DESY (simulated)	*+ 0.55 MHz*
pre-stressing half cell (measured)	*+ 0.10 MHz*
pre-stressing three TESLA cells (measured)	*+ 0.22 MHz*
required frequency @ 300K	***1298.9 MHz***

The correct frequency at room temperature mainly depends on cool down shrinking, additional chemical treatment and pre-stressing of both cavity tuners. These tuners permit an axial deformation of ±400µm and ±500µm for the half cell and the three TESLA cells, respectively. The induced frequency shifts have been taken into account. Thus, the estimated tuning frequency follows from Table 2.

Table 3: field detuning caused by pre-stressing half cell

	Gun Cell	TESLA1	TESLA2	End Cell
detuning axis field	***-7.3%***	***-1.8%***	***+1.4%***	***+3.1%***

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A non-negligible detuning of the π-mode field, as shown in Table 3, is caused by pre-stressing of the half cell. This measurement has to be considered inversely by pre-tuning to obtain the right field profile in the cryostat.

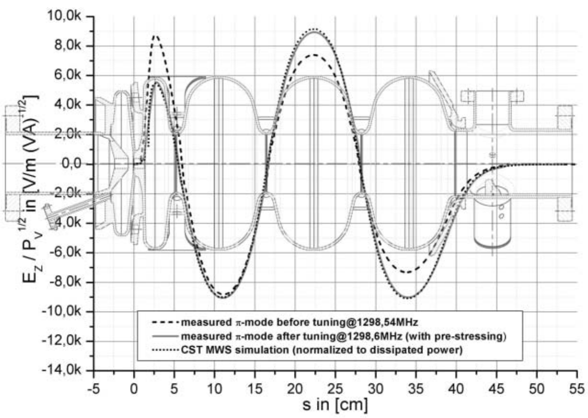

Fig. 2: measured vs. simulated π-mode field profiles before and after tuning.

Based on these target values, the tuning process was realized as presented in [3]. It succeeded in the measured field profile shown in Fig. 2 and met the calculated requirements.

EXT. Q STUDY MAIN-COUPLER

In order to maximize the rf power transfer from klystron to the electron beam, it is absolutely necessary to match the coupling. The applied Rossendorf main coupler is not adjustable, thus the antenna is optimized for maximum beam power with an external quality factor of:

$$Q_{ext} = \frac{Q_0}{1 + P_{beam} / P_C} = 2.7 \cdot 10^7 \qquad (1)$$

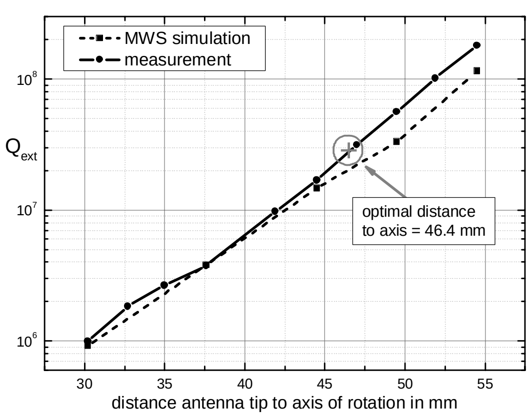

Fig. 3: external quality factor vs. antenna length.

The determination of the suitable distance between antenna tip and axis of rotation is done by an additional probe antenna added at the opposite side of the cavity at room temperature. As shown in equation 2 one has to measure incident and reflected power at the input port, the transmitted power at the main coupler as well as the unloaded quality factor of the cavity.

$$Q_{ext} = \frac{Q_0}{\beta_{ext}} \quad with \quad \beta_{ext} = \frac{P_t}{P_i - P_r - P_t} \qquad (2)$$

The results presented in Fig. 3, point to the best coupling at a distance of 46.4 mm from axis. An additional calculation, using the results of MWS©-simulations with different boundary conditions as shown in [4], gives a similar performance.

TUNING HOM-COUPLER

We use the welded DESY TTF II HOM-couplers. Due to the asymmetric design caused by the cathode and its cooling support, both couplers are welded to the coupler section at the end of the beam tube. To estimate the precision achieved by trap circuit tuning, we measured the external quality factor at the π-mode frequency versus tuning displacement and frequency shift. To prevent crosstalk it is necessary to place the input antenna probe at the opposite side of the HOM couplers. The result is presented in Fig. 4. It is obviously hard to get a better external quality factor than $Q_{ext}=10^{11}$. In that case less than 10% of the dissipated power is transmitted out of each HOM-coupler.

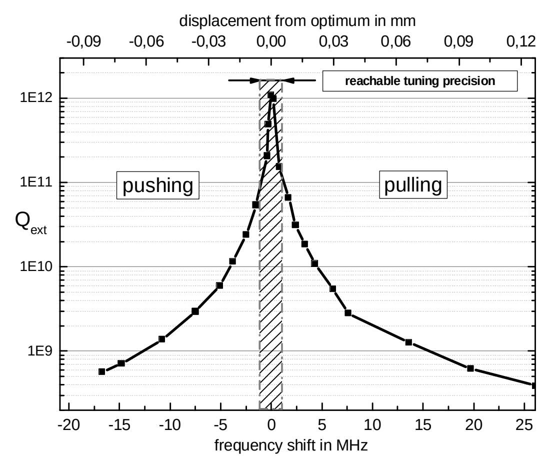

Fig. 4: external quality factor vs. detuning from best π-mode suppression.

TUNING CHOKEFILTER

The choke filter is situated next to the first gun cell and described more in detail in [5]. It prevents the leakage of RF power through the coaxial line out of the cavity which is caused by the cathode and its coupling to the gun cell. The filter is designed as a coaxial trap filter. Its band pass frequency will be adjusted during the assembling of the cryostat. To estimate the transmitted power, we measured the external quality factor versus detuning of the choke cavity by crushing and stretching. For this purpose an antenna probe with the same diameter as the original cathode was used. Thus the power behind the choke filter depending on the dissipated power through the walls can be measured (Fig. 5).

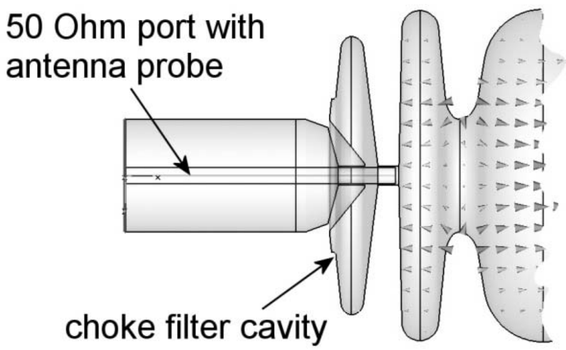

Fig. 5: assembly to measure π-mode suppression.

As a result one gets a tuning curve shown in Fig. 6. Because of mechanical tolerances during the assembling of the cryostat, it is hard to improve the accuracy better than ±100 microns. Within this range, the external quality factor is better than $Q_{ext}=10^{12}$ and the transmitted power behind the choke is less than 1% of the dissipated power. An additional MWS simulation yielded comparable results.

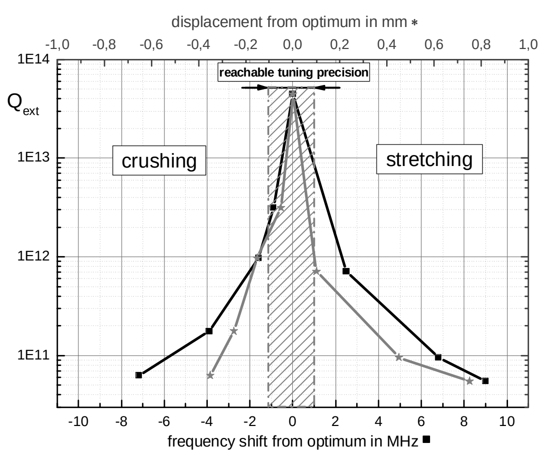

Fig. 6: external quality factor vs. choke filter detuning measured by frequency shift and deformation.

1ST VERTICAL COLD TEST

Following the tuning procedures the cavity was prepared at DESY Hamburg by buffered chemical polishing (40μm BCP) and high pressure rinsing (HPR). Afterwards the cavity was tested in a vertical cold test, as described in [6]. During the cool down from 4.4K to 1.6K the unloaded quality factor was measured at low rf power (Fig. 7). The illustrated surface resistance follows from eq. 3 and the numerical calculated geometry factor G.

$$R_S = \frac{G}{Q_0} \quad with \quad G = 241.9\Omega \tag{3}$$

$$R_S = A_S \bullet \omega^2 \bullet \frac{1}{T} e^{-\frac{\Delta}{k \bullet T}} + R_{res} \quad \text{für} \quad T < T_C / 2 \tag{4}$$

Based on the BCS-theory the surface resistance can also be calculated analytically. Fitting the measured data points by using eq. 4 leads to the following material parameters:

$$A_S = 2.42 \bullet 10^{-15} \frac{\Omega \bullet {}^\circ K}{Hz^2} \quad ; \quad \Delta = 1.53 meV \quad ; \quad \underline{R_{res} = 3.43 n\Omega}$$

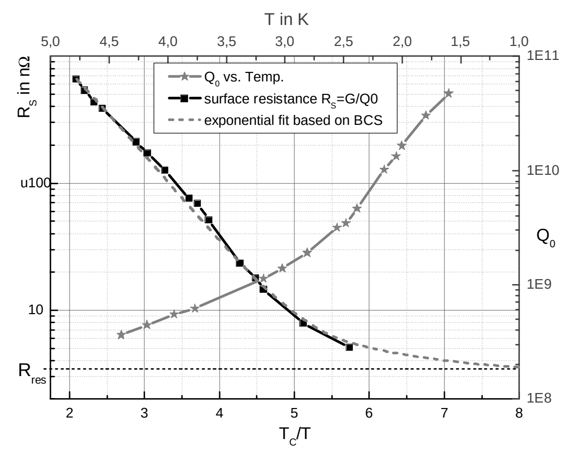

Fig. 7: surface resistance and unloaded quality factor versus temperature.

In view of the measured, unloaded high quality factor Q_0(@1.8K)=$3x10^{10}$ and the calculated low residual resistance of R_{res}=3.4nΩ the preparation of the cavity proceeded well.

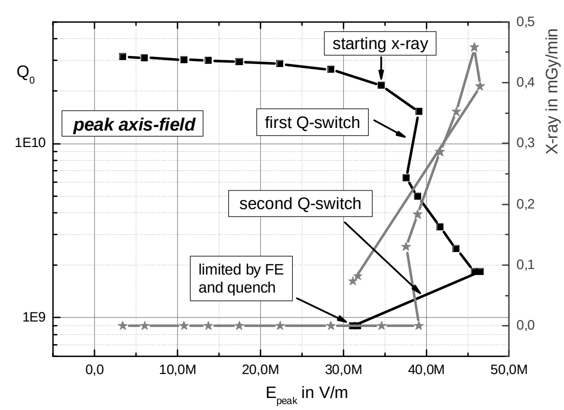

Fig. 8: Q_0 vs. peak axis field E_{peak} @1.8K.

Another matter of substantial interest is the Q vs. E chart. The corresponding measurement also takes place at DESY. In order to get comparable values, Q_0 is plotted versus peak axis field in the TESLA cells (design value

E_{peak}=50MV/m). Furthermore the radiation caused by field emitters is included into the same chart. As shown in Fig. 8 field emission started early and the quality factor decreases. Further increasing of rf power results in strong field emission and two Q-switches, which are probably caused by thermal breakdown at activated field emitters. After the second Q-switch the field was limited by quench. Especially the behaviour the Q-switches are most likely due to defects in the bulk niobium or to surface pollution. This might be induced by the hardly cleanable choke filter. Because of the narrow cathode feed through between choke filter and gun cell, direct cleaning of the filter cell wasn't feasible. Furthermore contaminated water runs out of it into the cavity which leads into polluted surface.

CONCLUSION

So far all measurements and tuning procedures yield acceptable results. In the next steps an improved HPR and BCP treatment will be established to achieve the designed peak field. Nevertheless the reached field of E_{peak}=39MV/m and the high quality factor of $Q_0=1.5x10^{10}$ demonstrates first of all the proper design of the gun cavity.

ACKNOWLEDGEMENT

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