

# COMMISSIONING OF THE UPGRADED SUPERCONDUCTING CW LINAC ELBE

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## Abstract

In January 2012 the 10 kW CW klystrons (CPI VKL7811St) used to operate the superconducting cavities of ELBE since 2001 have been replaced by pairs of 10 kW solid state amplifiers (SSPA) providing 20 kW RF power per cavity. The paper gives an overview on the activities and the problems during high power CW operation.

## ELBE RF UPGRADE

The intention is to double the accelerated electron (CW) current from 850  $\mu$ A to 1.6 mA [1].



Figure 1: High power CW operation at ELBE.

The replacement of the klystrons by SSPA is illustrated in Fig. 2. Two 10 kW SSPA modules are used per cavity and one SSPA is used to operate the SRF photo gun. The RF related activities before the upgrade project are described in the paper [2]. Figure 3 shows the new SSPA gallery at ELBE. In general the ELBE operation is now much smoother than with the klystrons used before.

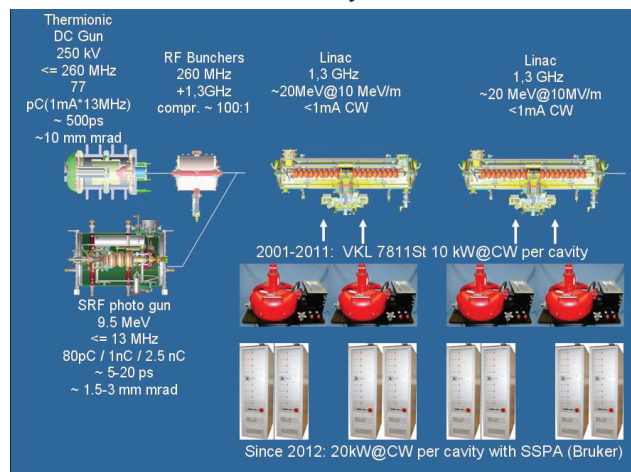


Figure 2: Layout of the upgraded ELBE RF-system.



Figure 3: The new SSPA cabinet at ELBE.

## MATCHING THE PAIR OF SSPA

The block diagram of the setup is shown in Fig. 4. Two 10 kW SSPA are operated in parallel using hybrid waveguide couplers at the output and also 3 dB hybrid couplers (SMA-type) at the input. For the adjustment of amplitude and phase the waveguide was shorted. The fully reflected RF power was terminated by the water load of the circulator (both manufactured by S.P.A. Ferrite Ltd., St. Petersburg/Russia).

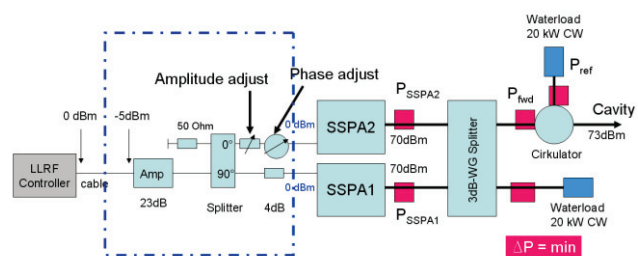


Figure 4: Block diagram of the 20 kW SSPA module.

Tuning criterion is RF power minimum at the isolated port of the 3 dB-waveguide coupler. Best match is obtained when the setup is tuned at full RF-power. Fig. 5 illustrates a power sweep of a matched pair of SSPA. The sum and the difference power are displayed. If one tunes the amplifier pair at low power the match at high power becomes unbalanced. First step is to adjust the driver circuit for equal RF power at both SSPA outputs. Next step is to minimize the power DP (fig. 4) at the isolation port of the waveguide coupler using both adjustment knobs of the driver.

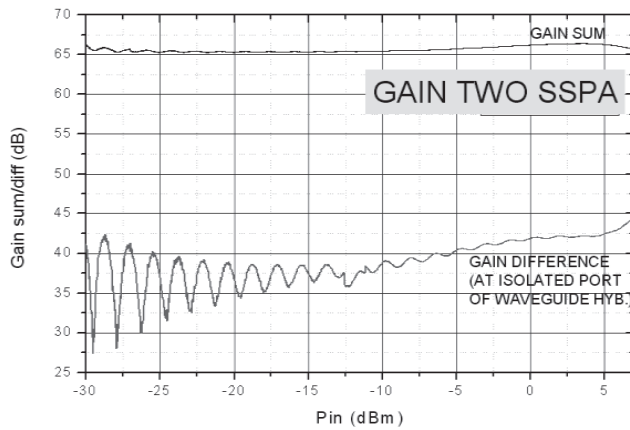


Figure 5: Sum and difference power at both ports of the waveguide coupler, (power sweep).

The cavity bandwidth of the superconducting cavities has been increased from 100 Hz to 225 Hz to reduce the reflected power during high current operation. Because the ELBE RF-coupler is equipped with a fixed antenna tip the bandwidth has to be changed with 3-stub waveguide tuners. Figure 6 shows the forward and the reflected RF-power plotted against the beam current for 100 Hz and for 225 Hz cavity bandwidth. One can derive from Fig. 6 that the higher bandwidth drastically reduces the reflected power at higher beam current.

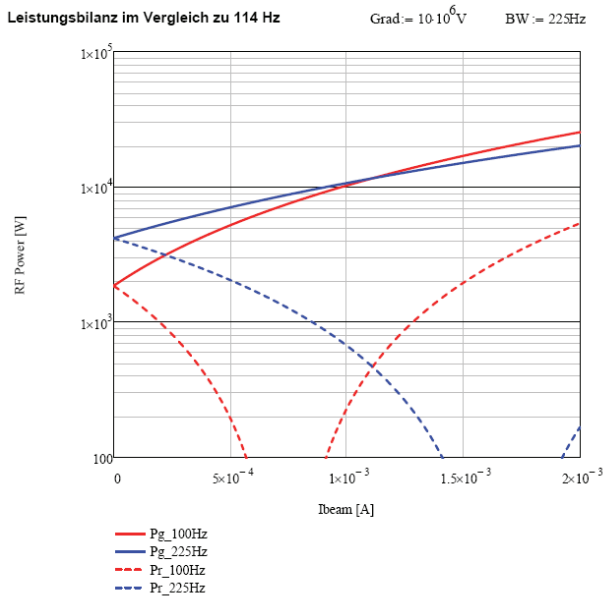


Figure 6: Forward ( $P_g$ ) and Reflected RF power ( $P_r$ ) vs. beam current ( $I_{\text{beam}}$ ) at different cavity bandwidths.

## THERMAL PROBLEMS DURING OPERATION WITH HIGH BEAM CURRENT

The hardware used for beam diagnostic, beam measurement and supervision was designed for a maximum beam current of 1 mA. Electronic components

(hard- and software) had to be modified to handle beam currents up to 2 mA. Also thermal problems have been observed and evaluated, in particular:

- Overheating of the waveguide windows,
- Arcing at the waveguide windows,
- Overheating of the beam dump windows,
- Overheating at the RF coupler

### Overheating of the Waveguide Windows

The “Rexolite” waveguide windows at ELBE have been used from the beginning in 2001. Rexolite is a cross linked polystyrene, (thermal conductivity: 1.2 W/m K and RF loss factor 0.0002 @1GHz). At 20 kW RF power (CW) the thermal load of about 4 W per window is expected. In Fig. 7 the measured surface temperature of the window is plotted against the beam current. For safety reasons additional air cooling has been provided to keep the maximum temperature at the waveguide window below 60°C (Fig. 8).

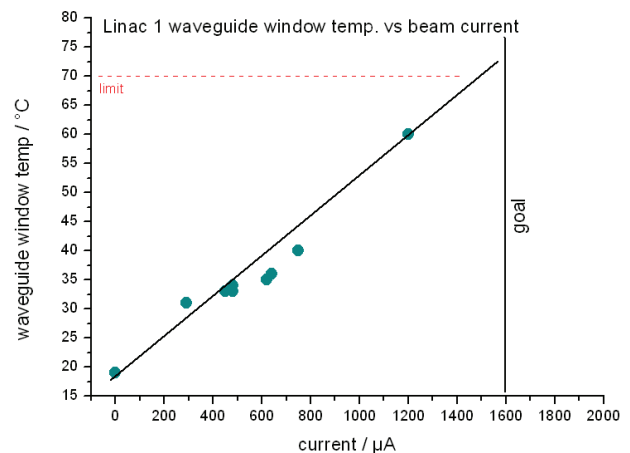


Figure 7: Measured surface temperature of the waveguide window versus beam current.

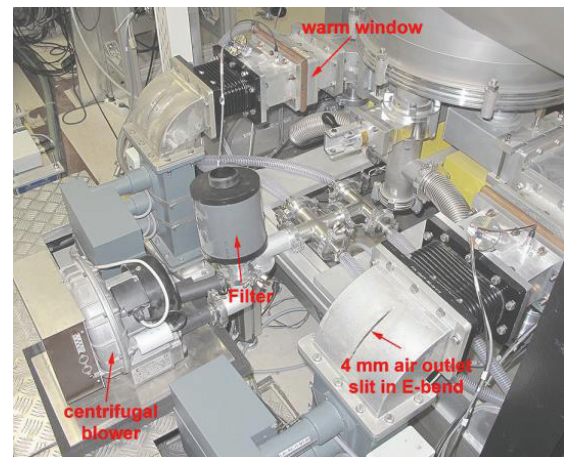


Figure 8: RF port of two cavities at ELBE. The waveguide window is called warm window.

The air is produced by centrifugal blowers. Jet nozzles are used to cool the window. The air is removed from the waveguide by air outlet slits in the E-bends (Fig. 8). The slit was modelled before to ensure RF safety (Fig. 9).

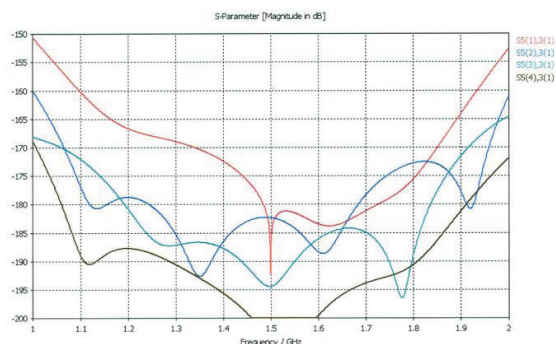


Figure 9: Attenuation of different waveguide modes (E-bend slit:  $l=100$  mm,  $w=5$  mm, thickness 5 mm).

### *Arcing at the Waveguide Windows*

The waveguide windows are equipped with photomultipliers and pyrometers (Fig. 10).

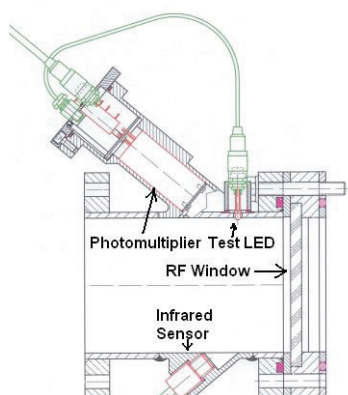


Figure 10: ELBE waveguide window with sensors.

Experience has shown that operation at high beam current (CW) is possible without notable light events. But in the so-called “macro-pulsed mode”, in which case the beam is pulsed in the injector, the risk of light events is increased. The standing wave pattern on the position of the waveguide windows is shifted during the mismatch caused by the pulsed beam load of the cavities. Sometimes the high local gradient produces arcs at the waveguide windows. The windows can be trained using pulsed RF. This must be done after breaking the vacuum during shutdowns, but training sometimes also helps to reduce arcing between shutdowns. The matter is subject to further investigation at ELBE.

### *Overheating of the BeO-beam Dump Windows*

The ELBE beam lines are terminated by beam dumps using graphite cones to dump the beam and radiation cooling to dissipate the heat to water cooled copper blocks. At the entry of the beam dump BeO-windows are used to protect the beam line vacuum against possible dust from the dirty graphite cones (Fig.11). The overheating of the BeO-window has been reduced using beam sweepers. A beam sweeper is performed by vertical and horizontal steerer coils (inductance 9 mH) driven by independent sinusoidal current sources.

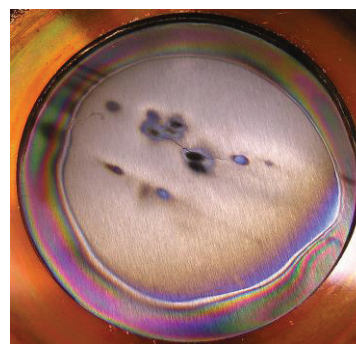


Figure 11: Hot spots at the BeO-beam dump window.

For the highest beam current of 1.6 mA the sweep frequency for the given design has to be above 100 Hz to avoid critical local temperatures. The beam line has been equipped with a telescopic sight to optimize the parameters of the beam sweeper during operation. The setup is now in permanent use.

### *Overheating at the RF Coupler*

The coaxial ELBE RF couplers, shown in Fig. 12, are equipped with conical ceramic windows (Alberox). The outer coax part is cooled with liquid nitrogen. The temperature of both coax parts rises with increasing RF-power fed to the cavity. During high power CW operation at 1.6 mA the N<sub>2</sub>-temperature at the outer coax part rises from 77 K to 112 K. No related problems have been observed so far.

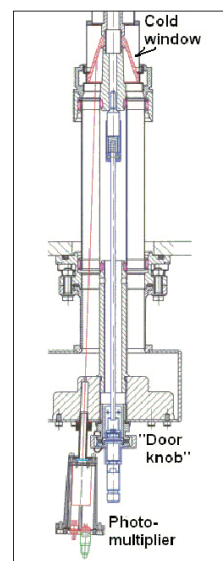


Figure 12: The ELBE coaxial RF input coupler. The outer side of the cold window is cooled with liquid nitrogen.

## REFERENCES

- [1] H.Büttig et.al., NIM A 704 (2013) 7-13.
- [2] H.Büttig et.al., NIM A 612 (2010) 427-437.
- [3] H.Büttig et.al., Proc.ARD workshop 2013, Dresden, <http://indico.cern.ch/materialDisplay.py?materialId=6&confId=223797>