

RESULTS OF ELBE WINDOW AND COUPLER TESTS WITH A RESONANT RING

A. Buechner, H. Buettig, R. Schurig, G. Staats, A. Winter (FZD, Dresden)

Abstract

A new test bench based on a resonant ring has been built at ELBE to run window as well as coupler tests. The resonant ring is driven by a 10 kW klystron and allows tests with RF power up to 100 kW in CW mode and about 200 kW in pulsed mode. Coupler tests are done with liquid Nitrogen cooling under almost real conditions. The results of warm window and coupler tests in pulsed and CW mode will be presented. Also details about the ring and a special designed coupler tip to rectangular waveguide transition are given.

INTRODUCTION

The ELBE accelerator operates with 10 kW klystrons per cavity in true CW operation [1]. RF-couplers with a fixed antenna tip length, optimized for an operation bandwidth of 114 Hz at 1.3 GHz, and separate warm windows are used. The RF coupler is based on a development by HEPL at Stanford, which uses a design by Mark Champion [2]. The coupler has a conical ceramic window. The warm window is made from polystyrene (Rexolite[®]) which is not very common as RF window material in accelerators. The window is a standard microwave part for WR650 waveguides. This gives a mechanically very simple and cost effective window design compared to ceramic windows. Two cryomodules with two cavities each equipped with two identical couplers and warm windows are installed. This setup is in operation without problems since 2001 but is not completely RF-trip free.

Coupler and window tests and training were done with a test stand [3]. But this was limited by the available klystron power of 10 kW. Also the training conditions were far from reality. The coupler could only be operated at room temperature and only with vacuum at the coupler tip side. The RF matching was poor.

THE RESONANT RING

To overcome the power and test limitations a new test bench based on a resonant ring was built within the EUROFEL framework (Figure 1).

A new control hardware was built, too which processes 16 interlock signals and is used for controlling the RF power amplifier (e.g. klystron). 4 temperatures, 3 vacuums and 4 RF levels are measured and logged. Test signal generation and data acquisition of all analogue signals is done with a National Instruments USB-6221 data acquisition board. For data logging and user control a Windows-PC is used. The interlock part is completely independent from the LabWindows user interface software running on the PC.

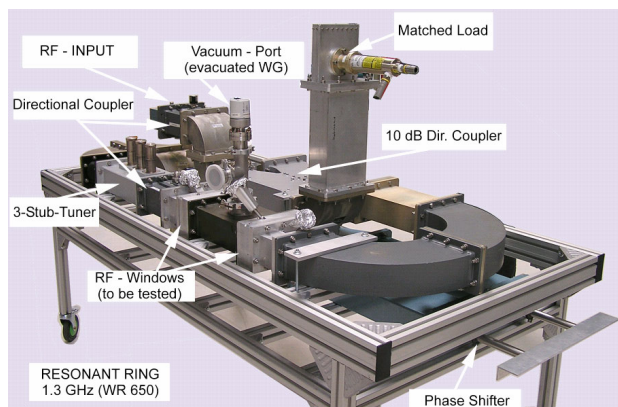


Figure 1: Resonant ring at ELBE.

The following 3 processing modes are foreseen:

- Field processing implies low thermal load at the device under test and is done with pulses of 10 ms pulse duration and 300 ms repetition rate.
- Thermal tests are done with constant CW power. Any Interlock (light, vacuum or temperature) stops processing.
- Mixed mode with pulse trains of 10 pulses from 1 ms to 1 sec is a combined test procedure to apply high gradients as well as significant thermal load. Interlocks reduce repetition rate as well as power.

Generally the output power of the klystron is stabilized with its own control loop. The power step was chosen to 50 W at the klystron which is about 1 kW in the ring.

BEHAVIOR OF THE RESONANT RING

The ring acts like a travelling wave resonator and shows the typical resonance curve. The gain of the ring without insertions is more than 25. Careful adjustment of the phase shifter and the 3-Stub-Tuners is required to reach maximum gain. This decreases also the reflected wave in the ring below the measurement accuracy.

At high CW power surface losses of the waveguide become dominant and decrease the gain. Some waveguide parts got seriously hot. At 100 kW CW operation the gain decreases over time from 25 to 6 and could not be completely compensated by retuning the ring with the phase shifter. Stable CW operation is possible till 50 kW.

WARM WINDOW TEST RESULTS

The setup for the waveguide window tests consists of two air-cooled waveguide windows inserted in the ring (shown in Figure 1). The maximum ring gain decreased to about 23.

A cut-off tube welded into an H-bend was used to apply infrared measurements. The RF-attenuation was estimated using CST and determined to be better than 80 dB. RF radiation measurements at 100 kW confirmed the calculation. Warm window temperatures are measured with a pyroelectric sensor on the cooled (air) side. An extra IR-camera was used to measure the surface temperature on one waveguide window during the operation.

A typical “training”-curve is shown in Figure 2. The first light interlocks occur above 70 kW, thereafter the achievable RF power is only 30 kW without interlocks. There was no improvement over a long time. Starting the procedure one day later the same effect was observed.



Figure 2: Typical training curve of a Rexolite® window.

An attempt was made with air on both sides of the window (no vacuum) because the warm window training was not very successful. In this case no light interlocks occurred in pulsed mode till the full power of the ring of 225 kW. The temperature behaviour of the windows could be measured under air without problems. In Figure 3 the temperature distribution with switched off cooling is shown. The temperature distribution on the cooled side with cooling is shown in Figure 4.

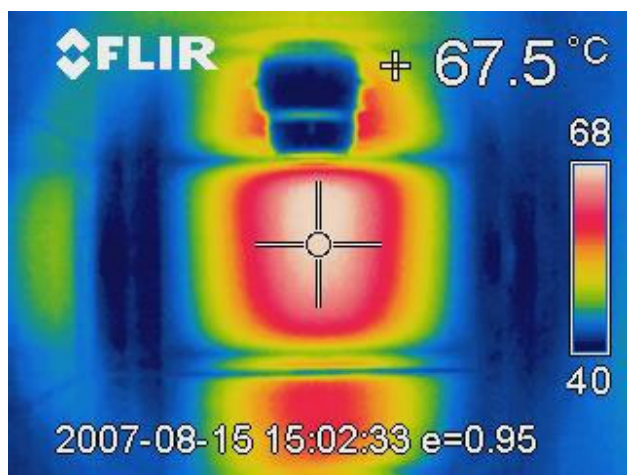


Figure 3: Thermogram at 19 kW CW without air-cooling.

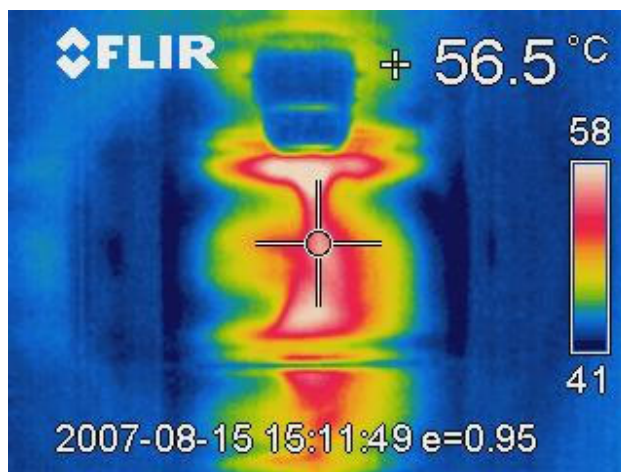


Figure 4: Thermogram at 55 kW CW with air-cooling.

From theoretical calculations it was already known about the high temperature difference between the cooled side and the uncooled side of the window because of the very poor thermal conductivity of Rexolite®. To study this one window was turned around to measure the temperature on both sides of the window. The temperature difference between cooled and not cooled side was 18 °C. The temperature of the not cooled side dropped down with time so the difference decreased after some minutes to 12 °C.

From these measurements and former tests it could be concluded that the Rexolite® warm window is capable to handle about 17 kW CW without cooling and about 50 kW CW with cooling. The temperature limit of the window interlock has to be decreased from 70 °C in the not cooled case to 55..60 °C in the cooled case because there is a temperature difference of about 15 °C at 50 kW CW between the two window sides.

COUPLER TEST STAND

For coupler tests the resonant ring was extended by an vacuum chamber as shown in the lower middle part of Figure 5. This chamber contains the coupler, which is connected to the waveguides at the upper end by a commercial doorknob transition and at the lower end (tip of the coupler) by an special constructed transition. The cold coupler part is cooled by liquid nitrogen. Two warm windows separate the vacuums at the cold window from the air in the ring. The overall gain of the resonant ring decreased to about 19.

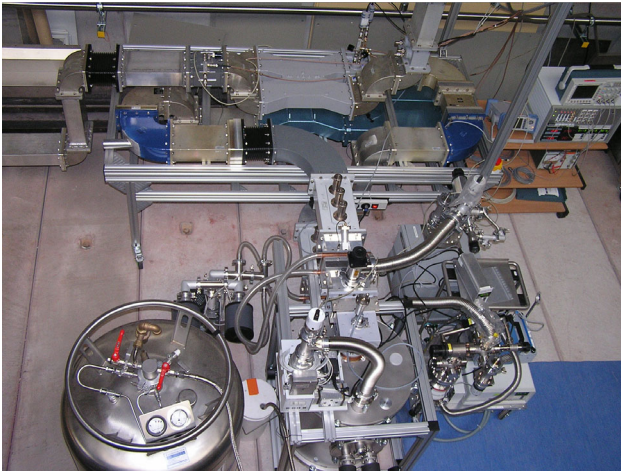


Figure 5: Coupler test stand.

In contrast to the later use of the couplers in the coupler test stand a transition from a rectangular standard waveguide WR650 to the coaxial line of the coupler is required. The coupler is not adjustable, so the wide range of coupler tip lengths which are needed for different coupling factors has to be considered. For testing the coupler at the test stand the same tips should be used as in the later application with the TESLA cavity. So it is not easy to find a simple, robust solution for the transition. This leads to the design shown in Figure 6 based on tip length variations from 30.2 mm up to 43.2 mm. It uses a rectangular standard waveguide WR650 with a circular mounting flange on the top for the coaxial coupler and a rectangular waveguide flange for the output. For best coupling the maximum possible length of the coupler tip inside the waveguide should be used, therefore the circular flange on the input is an integral part of the waveguide. By variation of diameter, height and position of the two cylinders this design is capable to adapt all the mentioned tip lengths of the different couplers which should be tested. Return losses of better than -30 dB are realistically obtainable.

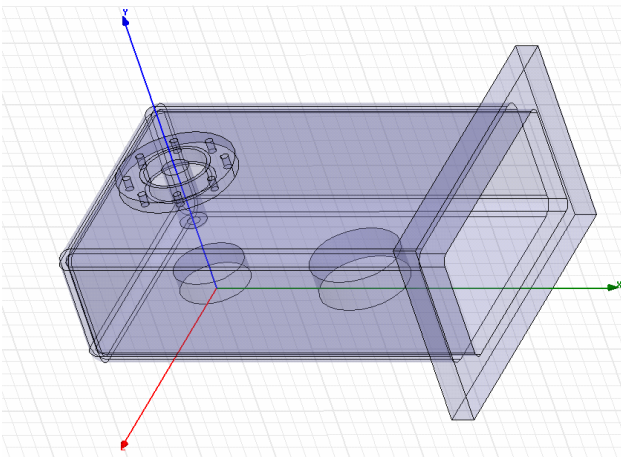


Figure 6: Design of the coaxial to waveguide transition.

RESULTS FROM THE COUPLER TESTS

Until now 2 couplers were tested. The maximum power level, which was reached with one coupler was 20 kW in CW operation for 8 hours of continuous operation and 30 kW in pulsed operation. The maximum power in CW operation is limited by thermal problems caused by bad contacts of the coaxial line between the coupler and the doorknob transition. Therefore carefully mounting and clean work is very essential. The other coupler which had a bad vacuum reached only 17 kW in pulsed operation. The limit in pulsed operation seems to be caused by the poor vacuum in the coaxial line which leads to a lot of light interlocks.

SUMMARY

The resonant ring has reached a gain of 23 with two warm windows inside and a gain of 19 with warm windows and coupler. Therefore it is possible to reach 230 kW respective 190 kW forward travelling wave power in the ring with 10 kW input power. However stable CW operation is only possible till 50 kW. At higher forward power in CW operation the ring heats up too much, the resonance shows a drift and the gain decreases.

In CW operation the tested warm windows are capable up to 50 kW power with air-cooling and without up to 17 kW. Temperature difference between warm / cooled side was about 15 deg @ 50 kW. To increase the maximum power level some training experiments were done, but no positive effects could be detected. First light interlocks have been detected in pulsed operation at power levels of 70 kW or above. To assume is an insufficient vacuum quality.

The first coupler tests have shown mixed results. One coupler showed distinct positive training effects and the ring power was driven from 25 kW at the beginning up to 35 kW in pulsed operation, the other not. In continuous CW operation 20 kW for 8 hours were possible. Probably the vacuum in the coupler is not good enough.

Although for RF systems like at ELBE with individually driven cavities and RF power sources of 10 kW the Rexolite® “plastic” waveguide window is a cost-efficient solution, it limits the overall performance by the achievable vacuum.

REFERENCES

- [1] A. Büchner, F. Gabriel, E. Grosse, P. Michel, W. Seidel, J. Voigtländer: „The ELBE-Project at Dresden-Rossendorf” EPAC2000, Vienna, June 2000, WEP3B04, p. 732-734
- [2] M. Champion: „Design, Performance and Production of the Fermilab TESLA RF Input Couplers“ LINAC96, Geneva, August 1996, TUP74, p. 521-523
- [3] A. Büchner, H. Büttig, J. Stephan, “RF Window Diagnosis and Training for the ELBE Superconducting Accelerator” Workshop on High-Power Couplers for Superconducting Accelerators, Jefferson Lab, Newport News, October 2002