CW test of the TTF-III input coupler at Rossendorf

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Introduction

While many laboratories plan to use TESLA-like cavities and/or cryomodules in CW regime, the TTF-III coupler [1] has never been tested in CW mode to find out what is its average power limit and what parts of the coupler would require upgrade/redesign for higher average power operation. ACCEL, BESSY, Cornell, DESY and Rossendorf agreed to collaborate on such a test of the TTF-III coupler. ACCEL manufactured one TTF-III coupler free of charge and assembled it on the test stand in clean-room condition. DESY provided the test stand, some additional hardware and its "know-how" in testing TTF-III couplers. Cornell provided IR viewports, instrumentation feedthroughs and its expertise and help during the coupler test and tried to coordinate joint efforts. BESSY participated in the test and offered a follow-up test in the new HoBiCaT horizontal test facility [2]. The test happened at Rossendorf at their 10 kWCW klystron test transmitter from June 14 to June 18.

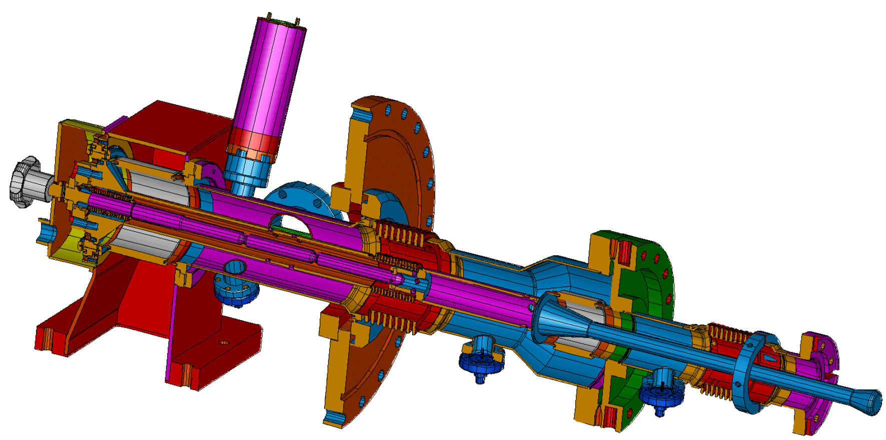


Figure 1: 3D view of the TTF-III input coupler.

TTF-III coupler

The TTF-III input coupler (Figure 1) was designed for high peak power required by TESLA cavities, but for an average power of only about 5 kW. It consists of two coaxial parts, "cold" and "warm", and a waveguide-to-coaxial-line transition. The cold, 40 mm diameter coaxial line has impedance of 70 Ohm. Its vacuum is common with the cavity vacuum and is separated from the warm line by a cylindrical ceramic window. The outer conductor of the cold line has bellows to facilitate coupling adjustment and alignment.

There is also a heat intercept connected to a 4.2 K thermal shield. A large conflate flange on the cold part of the coupler is anchored to a 70 K thermal shield. The warm, 62 mm diameter line has impedance of 50 Ohm. It is evacuated via a special port. The vacuum space in this part of the input coupler is separated from the air-filled waveguide by a cylindrical ceramic window in the waveguide-to-coaxial-line transition. Both inner and outer conductors have bellowed sections. The inner conductor bellows are cooled only by radiation and conduction via the cold ceramics. A metal rod inside the inner conductor serves for adjusting the antenna penetration. The inner conductor of the warm coaxial line and the outer conductors of both lines are made of copper-plated stainless steel. The wall thickness is 0.15 mm for bellows and 1.5 mm for straight pipes. The copper plating is 30 μm on the inner conductor parts and 10 μm on the outer conductor parts. The antenna is made of solid copper. Both ceramic windows are coated with TiN.

As couplers are susceptible to multipacting and arcing, there are four instrumentation ports (one on the cold coaxial line and three on the warm one) to mount *e*- probes and a light detector. These probes and detectors are used for monitoring and interlocking purposes.

Thermal analysis of the TTF-III coupler in CW regime indicated that the warm inner conductor bellow is the most critical component. That is why we paid special attention to monitoring temperature of this part during the test.

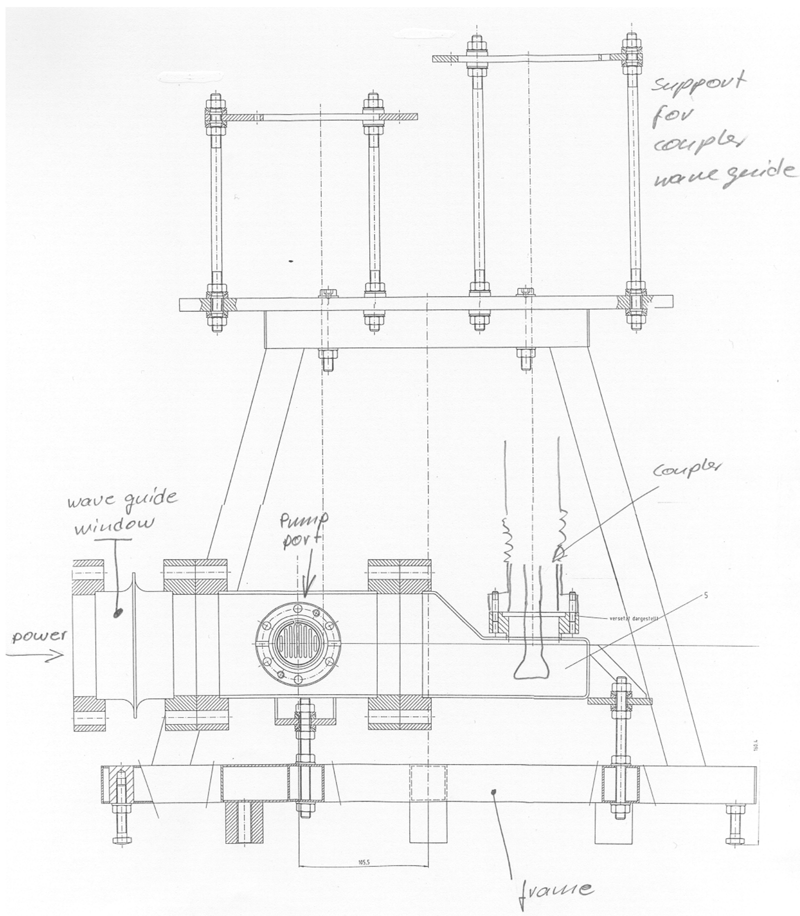


Figure 2: Single TTF-III coupler test stand with waveguide window.

Test set-up

The input coupler was mounted on a single-coupler test stand (Figure 2). A ceramic waveguide window is used to seal vacuum on the other end of the stand. Both cold and warm vacuum spaces were actively pumped with two turbo-pump systems. The test was performed at room temperature. The only cooling provided was cold-water (2.2°C) cooling of the 70 K flange. As the goal of this test was to study thermal behavior of the input coupler, all four instrumentation ports were equipped with IR viewports. IR sensors were attached to two of them. The tuning rod was removed and a PT1000 temperature sensor was attached inside the inner conductor next to the bellows. More temperature sensors were attached outside. Figure 3 shows location of all sensors used during the test. The input coupler waveguide was connected to the 10 kWCW klystron (CPI) transmitter (Figure 4). A water-cooled RF load was attached to the waveguide window side of the test stand.

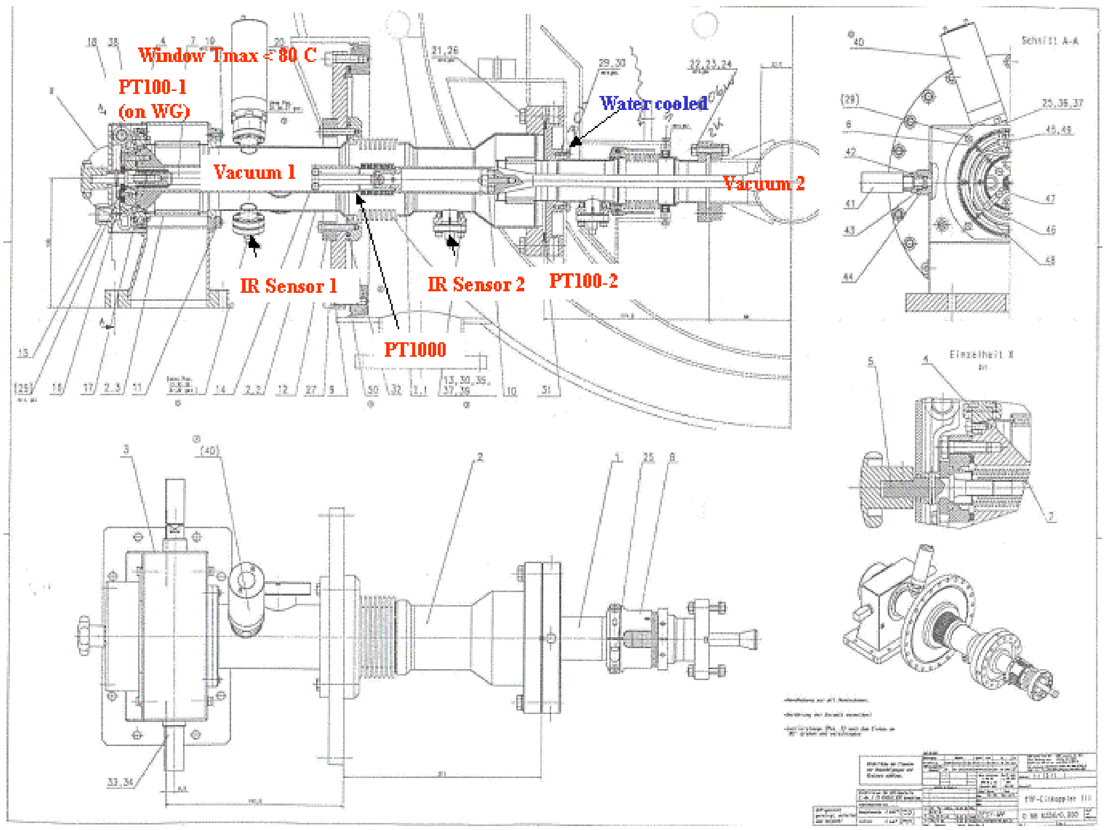


Figure 3: The input coupler drawing showing sensor locations.

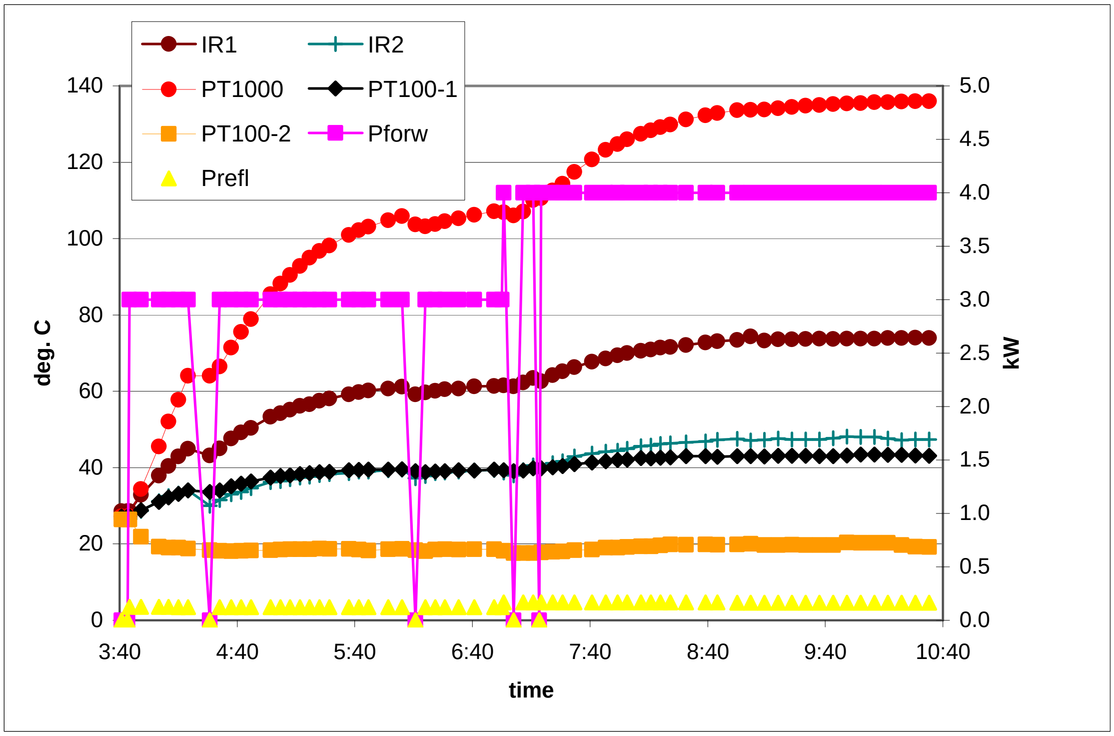
Figure 4: 10 kWCW CPI klystron inside a transmitter rack at Rossendorf.

Test results

The experiment set-up took two days. Then in the course of following two days (June 16 and 17) we gradually raised RF power to 4 kW in 1 kW steps. It took such a long time to raise the power because of a very long (estimated at 50 minutes) thermal time constant. The forward and reflected power signals, the vacuum in the cold and warm parts of the coupler, and the temperatures were recorded in an Excel spreadsheet every 5 minutes. At 4 kW, the PT1000 sensor located inside the inner conductor near the bellows, reached an equilibrium value of 136º. The temperature difference between 4 kW and 3 kW was 24ºC. Figure 5 illustrates the evolution of the temperature and the vacuum signals.

Comparison with computer simulations, predictions for the HoBiCaT test

Two computer programs have been developed to calculate the temperature distribution along TTF-III-like input couplers. One, written at DESY [3], is a MathCAD program. It uses RF fields calculated by MAFIA. The other program runs under MATLAB [4]. It assumes fields from analytical formulae for coaxial lines. Both programs can take into account radiation heat transfer and both produce similar results. Below we discuss the results obtained with the DESY program. All calculations are done assuming copper with RRR=10.



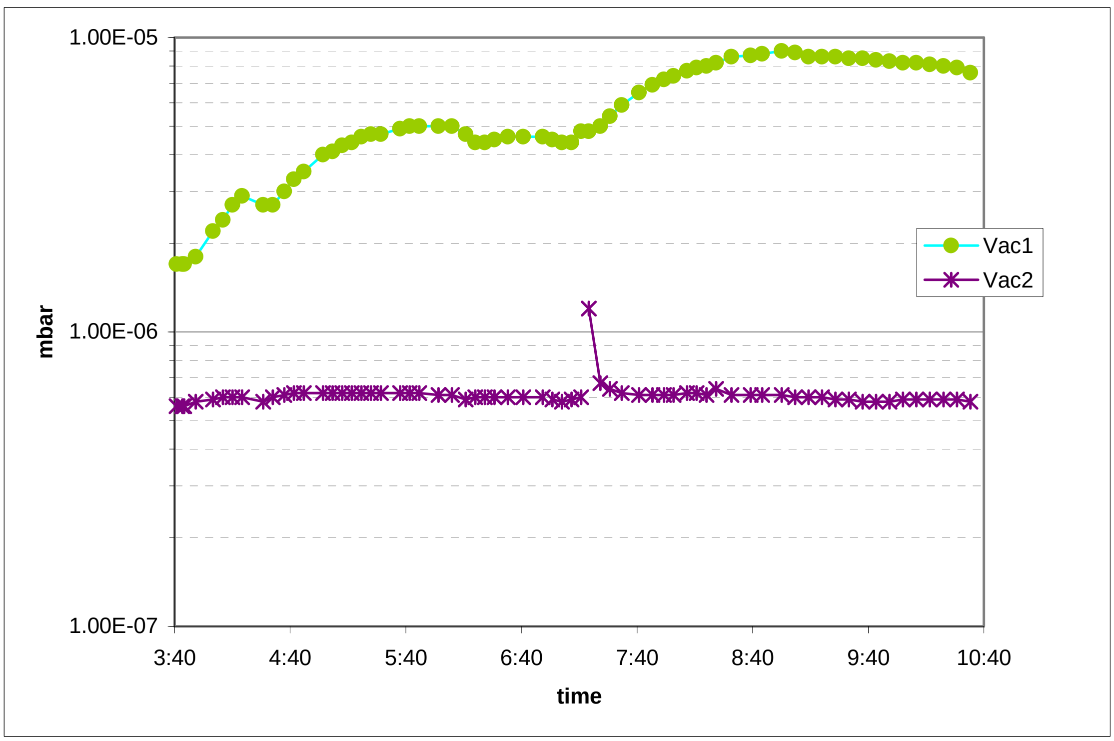


Figure 5: Evolution of temperature and vacuum during the final stage of the test.

The calculated maximum temperature of the inner conductor near the bellows is 163ºC when radiation heat transfer is not taken into account. It appears that heat radiation plays a role, even at these temperatures and should be taken into account for accurate predictions. As the emissivity of copper depends strongly on the surface quality, one cannot assume a handbook value but has to adjust it to match the measured temperature. An emissivity of 0.093 reduces the maximum calculated temperature to 136ºC equal to the measured equilibrium value. It also yields the correct temperature for RF power levels of 2 kW and 3 kW. For polished copper one can find emissivity values in the range from 0.016 to 0.052 (see references [5]), so 0.093 for copper plating seems to be reasonable value. Figure 6 illustrates the effect of radiation heat transfer for the Rossendorf test conditions.

One can now calculate maximum temperature for the proposed test in HoBiCaT (Figure 7). As stainless steel bellows should be able to easily withstand temperature as high as 400ºC, we expect to reach RF power of 10 kWCW with CPI klystron (klystron limited) and 15 kW with CPI IOT tube.

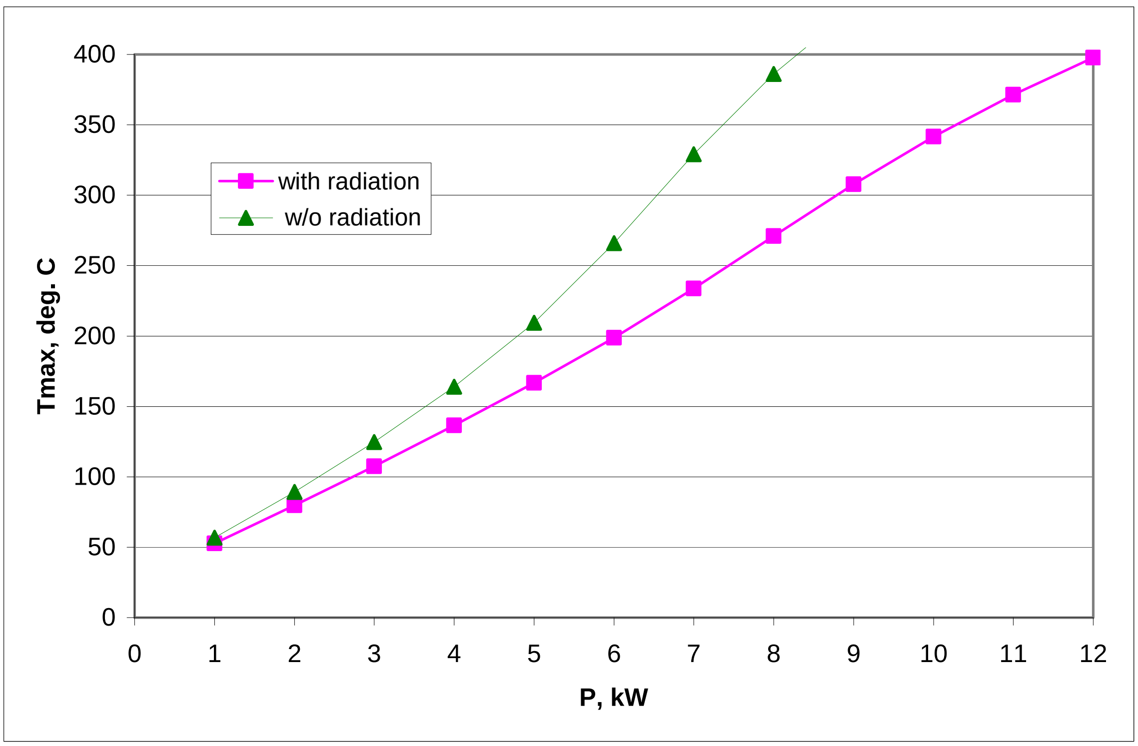


Figure 6: Maximum temperature of the warm inner conductor as a function of RF power with and without taking into account radiation heat transfer.

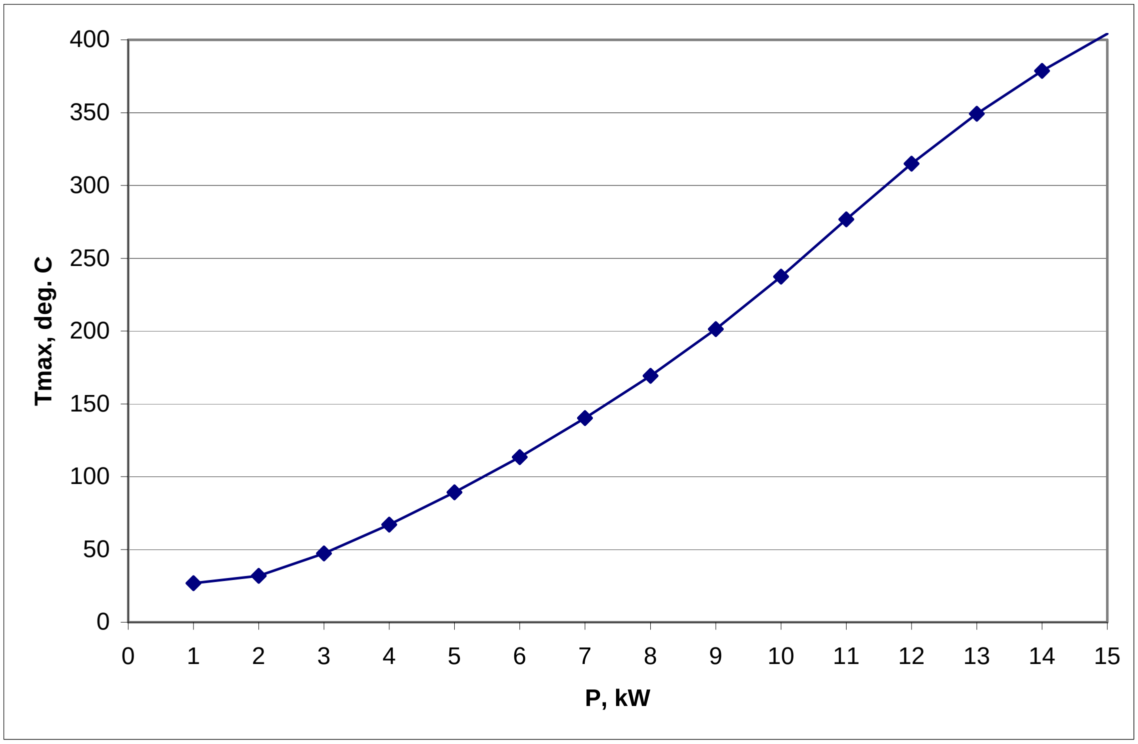


Figure 7: Maximum predicted temperature of the warm inner conductor for the HoBiCaT test.

Summary

The warm test at Rossendorf was the first CW test of the TTF-III input coupler. It allowed us to gain experience in such tests and calibrate computer codes used to predict the temperature distribution in the coupler. Without cryogenic cooling, a maximum temperature of 136 deg C was recorded at 4 kW CW (traveling wave) near the inner conductor bellows. Taking into account radiation heat transfer and adjusting the emissivity of copper to 0.093, one can match the maximum calculated temperature with that reached experimentally. Given this emissivity one can now predict the maximum average power capability of the TTF-III coupler under standard cryogenic conditions. The coupler is expected to handle at least 10 kW CW (traveling wave) when attached to a cavity and with appropriate cryogenic cooling. The proposed test in HoBiCaT will allow us to verify this prediction and test the input coupler in an environment close to that of a real accelerator.

References

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