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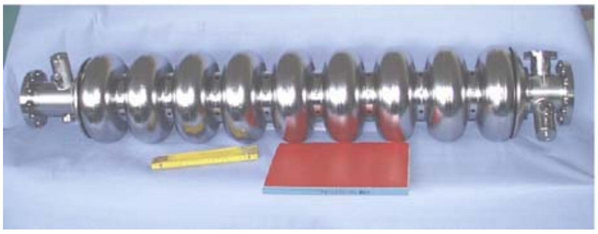

Deliverable 7.3.3:

"RF Conditioning studies of input power couplers for superconducting cavities operating in pulsed mode"

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Abstract

The superconducting cavity is the most important component of a superconducting RF acceleration system. But the so called auxiliary components like input coupler, HOM coupler or tuner need extensive care in design and performance to guarantee successful operation of the complete accelerating unit. In this work package alternative coupler to the TTF 3version were designed, built and tested. The main difference to the TTF 3 designed is a traveling wave section at the TW60 design and a larger diameter of the coaxial line for the TTF V coupler. In addition a TiN coating equipment for RF windows was built

Acknowledgements

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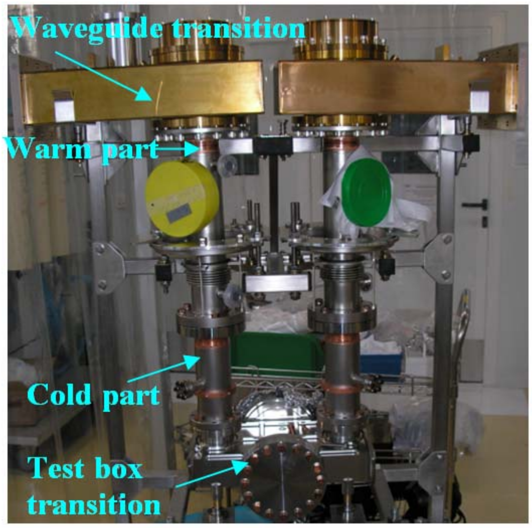
New Couplers

We have designed two new coupler prototypes named TTF-V and TW60 (Fig. 1 and Fig. 2). To validate these couplers it was decided to use the 'usual' TTF-III coupler conditioning procedure (see task 7.1.3). The next step should be the test of these couplers using a conditioning procedure with enough RF power constraints to make them competitive for the ILC project. At present the goal of the WP was the validation studies of these two prototype RF designs and realization concepts. This has been tested by using the TTF-III coupler processing procedure [1].

TW60 coupler prototypes



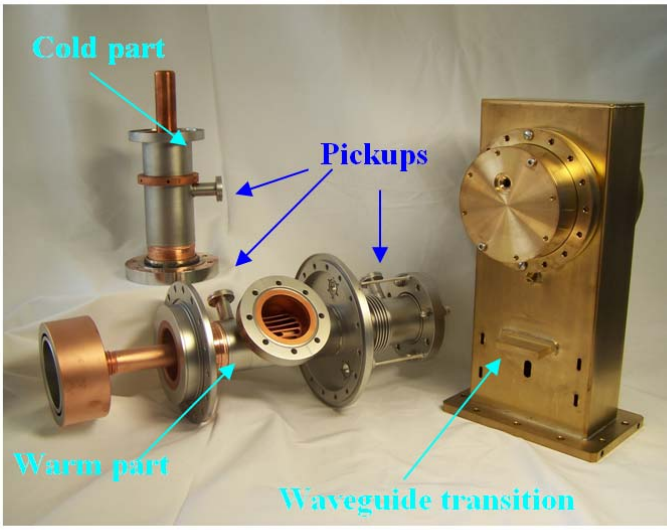
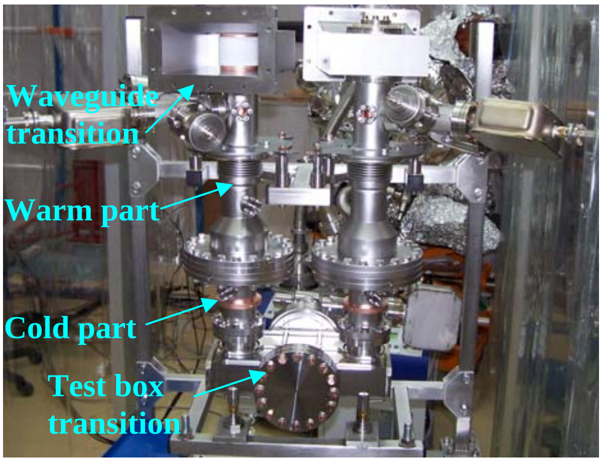


Fig. 1: TW60 coupler. The photo at the right shows the main coupler parts. The photo at the left shows an assembly of a pair of TW60 couplers using a test box transition.

TTF-V coupler prototypes



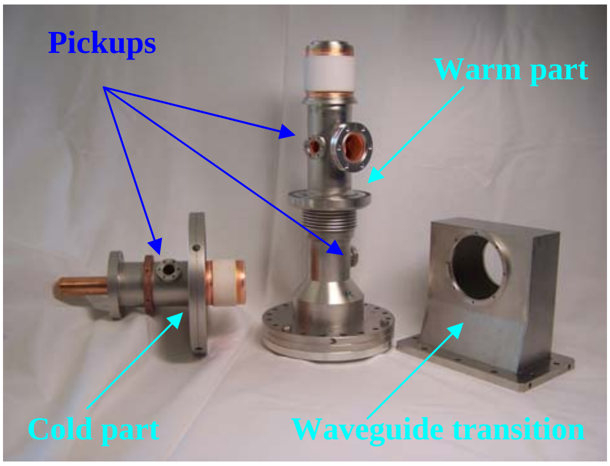


Fig. 2: TTF-V coupler. The photo at the right shows the main coupler parts. The photo at the left shows an assembly of a pair of TTF-V couplers using a test box transition.

After some problems at the reception of the couplers in having the correct frequency a solution was found by building a new transition box to adapt the antenna penetration and to adjust the frequency. The new test box was used for the assembly of one TTF-V coupler pair that was cleaned using the cleaning procedure for the TTF-III couplers. After the pumping-down and the in-situ baking of the TTF-V coupler pair, low level RF measurements was carried out. The scattering matrix parameters given by Fig. 3 showed a good matching of the two couplers.

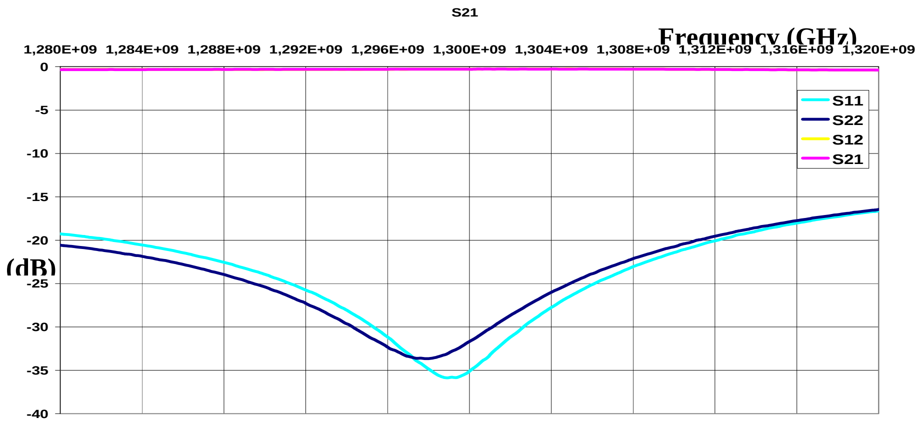


Fig. 3: Low level RF measurements on a TTF-V coupler pair with the new test box transition.

TiN coating of couplers

In the framework of task 7.2, several visits were made to our industrial partner, in order to follow different steps of machine assembly and to discuss about works to be undertaken.
Before sputtering machine reception in LAL, a representative of the laboratory who had followed this collaboration till the beginning, and who works on the machine actually, had spend one week making the first tests and checks. Once the process was validated and the contract terms were verified, the machine was ready to be transferred to LAL.
In the meanwhile, the fitting out of the local where sputtering bench will be installed at LAL was made. Partitions and ceiling installation, electrical and computer work as well as plumbing and ground painting were done. The end of this works was just on time before receiving the machine.

Figure 4: Sputtering bench local fitting

Machine delivery was the December 12th, 2007; and experts were present during machine reception and in situ installation. After checking the machine, in situ tests of the sputtering bench were made, which have lead to the acceptation of the machine.

Figure 5: Sputtering machine delivery at LAL

The machine is equipped with a pumping system (turbo-molecular and scroll pumps) that allows achieving a base pressure of 10^{-8} mbar in the vacuum chamber, before the introduction of ionization gas (Argon) and reactive gas (Nitrogen) and the starting of coating process.
In the both sides of vacuum chamber, the machine is equipped with a 10 inch titanium disc target of high quality (grade 2, minimum 99.7 % Ti). Two rotary magnet packs are placed just behind the targets to increase plasma density at their surface, and thus ameliorate sputtering yield (Figure 6-B). A special rotating sample holder was designed to permit uniform deposition on cylindrical ceramic windows (Figure 6-C). The machine permits also the RF etching of the substrate (Figure 6-D), a pre-treatment step in order to remove particle contamination, as it is not possible to clean ceramic with solvent due to the high porosity of the material and the possibility of solvent trapping. RF etching allows also enhancement of TiN adhesion by increasing substrate surface roughness.

Figure 6: Components of sputtering machine

(A) Titanium disc Target and vacuum chamber; (B) plasma confinement in target surface by rotary magnetron; (C) Sample holder; (D) RF etching.

A crystal quartz microbalance integrated to the bench allows following the deposit thickness and the deposition rate during the process.
In order to obtain a stoichiometric TiN, reactive sputtering process needs the optimization of gas and electrical parameters. Thus, the bench includes a mass flow controller for gas process (Argon) and reactive gas (Nitrogen), in addition to an adaptable power supply for each target.

The machine was used and in the following, we present first XRD analysis results of TiN_x deposits obtained by the new sputtering machine. During this parameter optimization step, all deposits were made on 10x10mm quartz substrates. The latter are cheaper than alumina substrates and suitable for XRD analysis. Deposits should be thick enough so that XRD analysis could be possible.

For a given bias and by maintaining constant Ar flow, the N_2 flow variation leads to different stoichiometry TiN_x films. XRD analysis was performed to control film stoichiometry. From the plot I = f (2θ) (where I is the intensity of diffracted X-ray and 2θ is the angle between X-ray source, substrate and detector), it is possible to determine spacing between the planes in the atomic lattice dhkl by applying Bragg's law:

$$d_{hkl} = \frac{n\lambda}{2\sin\theta}$$

(Where λ is the wave length of x-ray source, in this case we have a Cu tube with a λ of 1.54056Å)
Since TiN_x crystallize in a face centered cubic system for $0.605 \leq x \leq 0.999$, it is possible to calculate the lattice parameter for each deposit using the relation:

$$a_{TiN_x} = d_{hkl}\sqrt{h^2+k^2+l^2}$$

(Where (hkl) are Miller indices for diffraction planes)
Thus, by comparing the obtained values with the lattice parameter of stoichiometric TiN (aTiN = 4.239 Å), we can check the right reactive gas flows (N2) for a given electrical parameter and gas process (Ar).

Furthermore, from the obtained value a_{TiN_x}, it is possible to calculate x, the N-Ti ratio, by the relation:

$$a_{TiN_x} = 4.1925 + 0.0467\,x$$

thus, obtained the right stoichiometry of the film.

In the following table, we summarize the results obtained for several deposit at the same applied current of 3A and the same Argon flow of 0.1 sccm.

Table 1: lattices parameter and correspondent stoichiometry of deposits at different N2 Flow

Ar (sccm)	N2 (sccm)	I (A)	2θ	d (220) (Å)	a (Å)	x(TiNx)
0,10	0,11	3	61,8629	1,5012	4,2459	1,1423
0,10	0,12	3	61,8430	1,5003	4,2434	1,0896
0,10	0,13	3	61,8938	1,4992	4,2403	1,0223
0,10	0,14	3	61,9277	1,4984	4,2382	0,9775
0,10	0,15	3	62,1270	1,4941	4,2260	0,7153

Stoichiometric films obtained at these parameters have a deposition rate of 0.9 Ås-1. It is possible to modify this value by acting on substrate bias and/or gas parameters. However, this rate seems suitable, especially when we should deposit only few nanometers in a reasonable time. Figure 7 shows XRD graph, I = f (2θ), for some deposition represented in table 1.

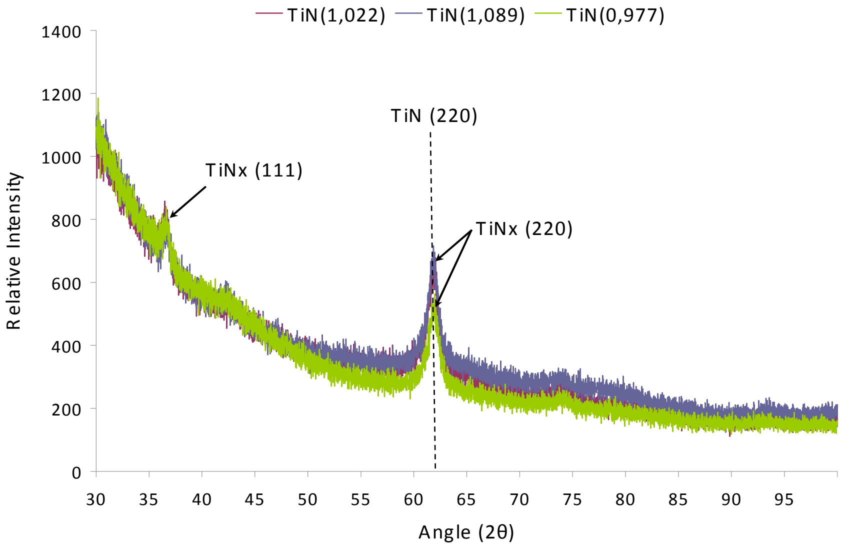


Figure 7: XRD plot for different TiNx deposits- comparison to stoichiometric film

Spacing between the planes in the atomic lattice dhkl is obtained by analyzing the peak (220) for each deposited film. The deposits seem have preferential orientation with the plane (220) parallel to the substrate surface. Lattice parameter aTiNx and x given in table 1 are also calculated according to the same plane.

Summarizing we can say that the first results show a very good stoichiometric ratio between Titanium and Nitrogen. The coating velocity deposition has been roughly defined and it will provide in the future the process parameters to define the procedure to obtain the nanometric films. The final goal of this task, to acquire the TiN coating technology, has been satisfied. Moreover this activity has been very successful and the direct impact is that our institute has decided to upgrade our coating laboratory spending an important budget to acquire a dedicated diffractometer that should be received and installed in the following months.

Conditioning

The conditioning of the TW60 coupler was restarted after about one year during witch they were stored under an active pumping. The long processing interruption was a consequence of some tricky troubles happened on the HV and electronic facilities. Our first aim was to restart the conditioning from the beginning in order to see if the couplers have conserved their last RF conditioning. We used 20 µs pulse widths with 2 Hz repetition rate. The increase of power was rapid for the first 500kW. Then the vacuum pressure increased and the power ramping rapidity started to be reduced. At 620 kW the first interlock happened. This power level is very near to the highest power reached during the first part of the conditioning in June 2007 (660 kW). This means that one year of storage under active vacuum have preserved the effects of the last conditioning.

Afterward, the conditioning restarted again. There was a lot of e^- interlocks correlated with vacuum bursts and reflected power (see Fig. 8). Also if the vacuum levels were generally very low during the conditioning (< 2 10^{-7} mbar) strong vacuum bursts happened several times. This means that to make conditioning possible we should use very strict vacuum threshold in order to limit the power ramping velocity. e^- currents were also very unpredictable. For these reasons, the operator had to change often the vacuum and the control loop parameters in order to adapt the used processing procedure to each situation in respect to the automatic procedure used for the TTF3 [1].

After some interlocks, the conditioning of the TW60 was achieved for the 20 µs pulses in 23 hours of effective RF power, by reaching 1 MW (the first part of the conditioning performed in 2007 is not considered). The effective RF time showed an acceptable performance in respect to the TTF3 [1] but we have to remark the presence of an important number of interlocks in this first phase at 20 microseconds. The conditioning of this coupler pair was totally finished after 36 hours (about 950 kW was reached for 400µs pulse and more than 500 kW for 1300 µs pulses), (see Fig. 8).

After the first ramp with the 20 µs pulses, in the other longer pulses we noticed a much reduced number of interlocks. However, a small arcing problem was noticed for some pulse lengths for high power levels. These arcs were due to some adhesion problems between the couplers stubs and the waveguide transition walls (see Fig.9). These arcs had no influence on the couplers behavior. Besides, they could be easily eliminated if there will have a next TW60 coupler version.

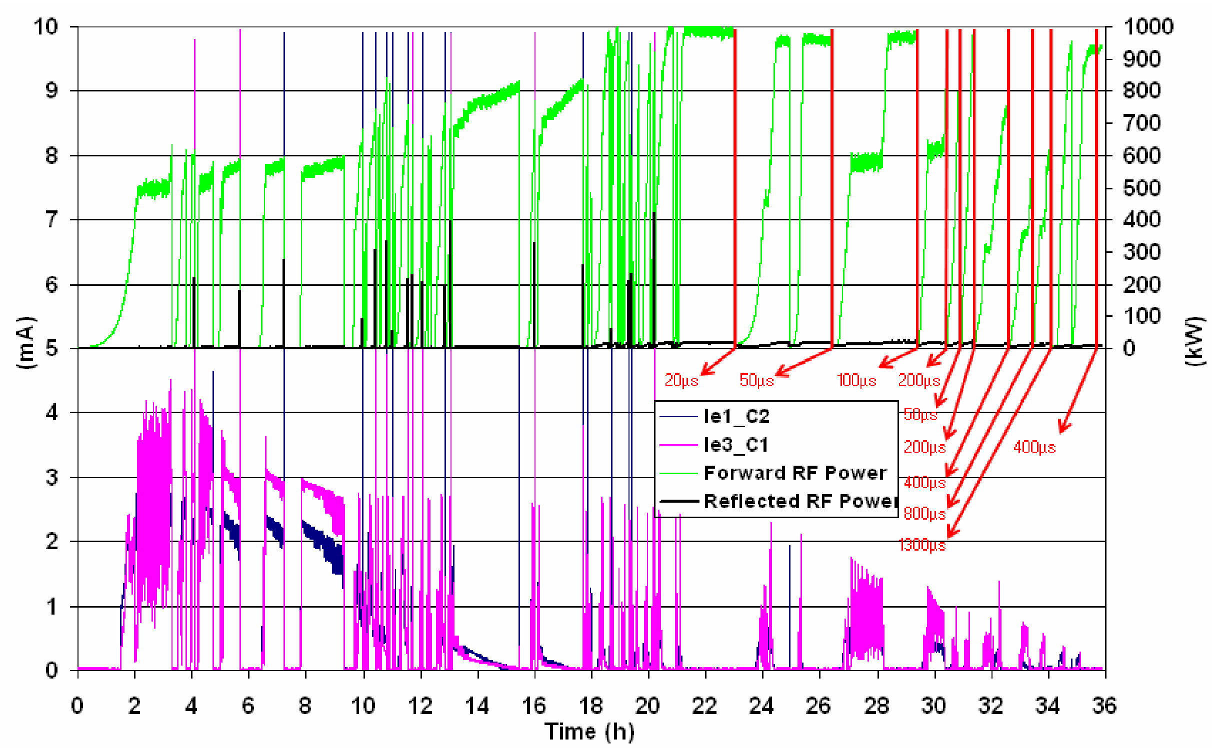


Fig. 8: Power variation during the RF conditioning of a TW60 coupler pair in June 2008. We can see the strong correlation between the e^- currents jumps with the reflected RF power. We only illustrated the behavior of the e^- current pickup of the cold part in the upstream coupler (Ie3_C1) and the e^- current pickup near the warm window in the downstream coupler (Ie1_C2), which were at the origin of the majority of the interlocks.

The diagnostics that activated the interlocks were always the same: the e^- current pickup of the cold part in the upstream coupler (Ie3_C1) and the e^- current pickup of the top part of the warm part in the downstream coupler (Ie1_C2). Their signals were correlated with the vacuum behavior. Since the highest signals were measured always in the same place, we suspect imperfection in these locations more than a systematic multipacting threshold acting at a certain power level.

To clarify this aspect we expect to condition a new pair of TW 60 at the end of 2008 – beginning 2009.

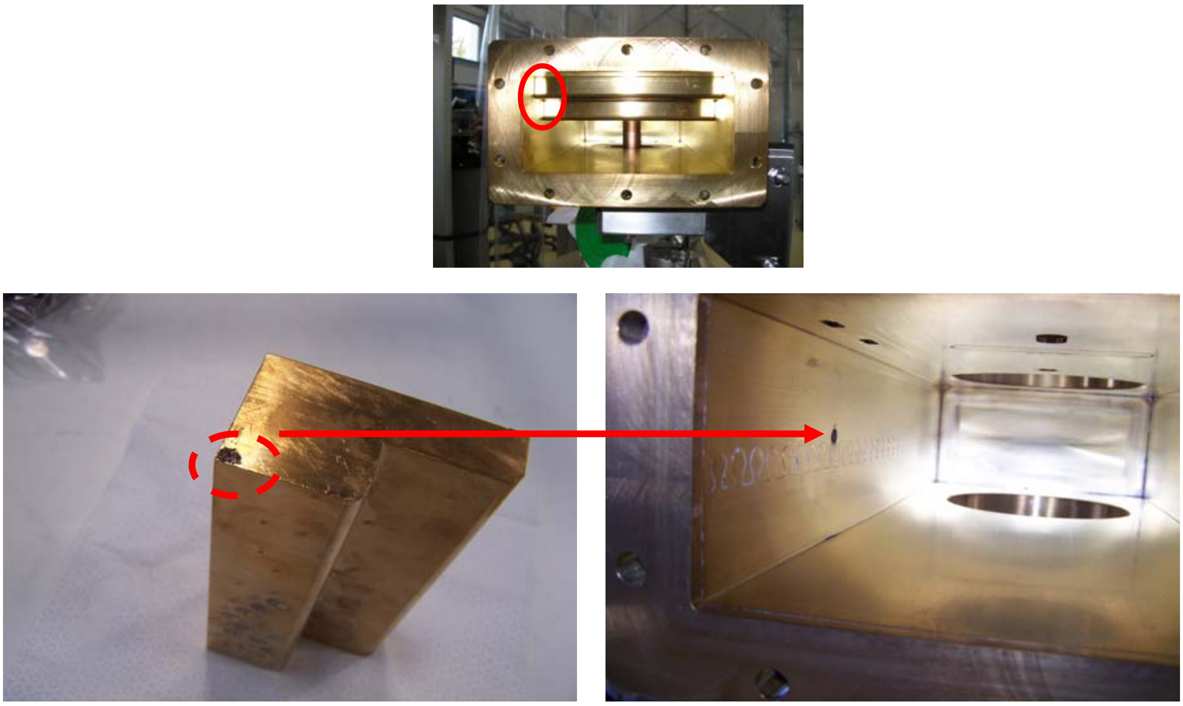


Fig. 9: Some arcs taking place in the waveguide transition of the TW60 during processing.

Finally, we believe that conditioning of the TW60 couplers could not be done, for the moment, in a totally automated procedure since this coupler pair behavior is totally different from the TTF-III one [1]. This is the reason for which this conditioning needs a permanent presence of an operator to adapt the procedure parameter to each stage of the RF conditioning.

Nevertheless the principal result is that we demonstrated, after the design and the realization of these new prototypes, that its behavior under high power conditioning is good. It reached 1 MW following the cycling used for the well tested TTF3 without showing any absolute limiting factor. The conditioning time was longer in respect to the TTF3 model [1] but this was expected since the design is completely new, some manufacture problems has been noticed during the realization phase and the conditioning procedure has been not optimized for this design (this is possible only with a strong statistical sampling that is not feasible for a limited number of couplers).

Since it has been validated this prototype should be modified in the future to ameliorate some technical details. This should bring to some advantages, especially in total costs since the planar ceramic windows can be much easily adapted at the brazing procedure.

The TTF-V coupler pair was, then, processed successfully with a cycle that is absolutely comparable to the TTF3 one [1]. The total RF conditioning was possible in 24 h only. Many e^- current interlocks were noticed during the first step of the conditioning, using 20µs length pulses. The origin of these interlocks was generally the high e^- current detected with the pickup Ie3_C1 located on the cold part of the upstream coupler. This current was specially enhanced between 200 kW and 300 kW. Its fluctuations were high enough to exceed the e^- current interlock level several times. No vacuum bursts were correlated with these interlocks. The maximum power of 1 MW was reached for the first time after about 17 hours. Afterward, the conditioning was continued using larger pulses (50 µs, 100 µs, 200 µs, 400 µs to reach 1

MW and 800µs, 1300µs to reach 500 kW). These steps of conditioning were relatively short and only one e⁻ current interlock occurred. It was also activated by the pickup Ie3_C1.

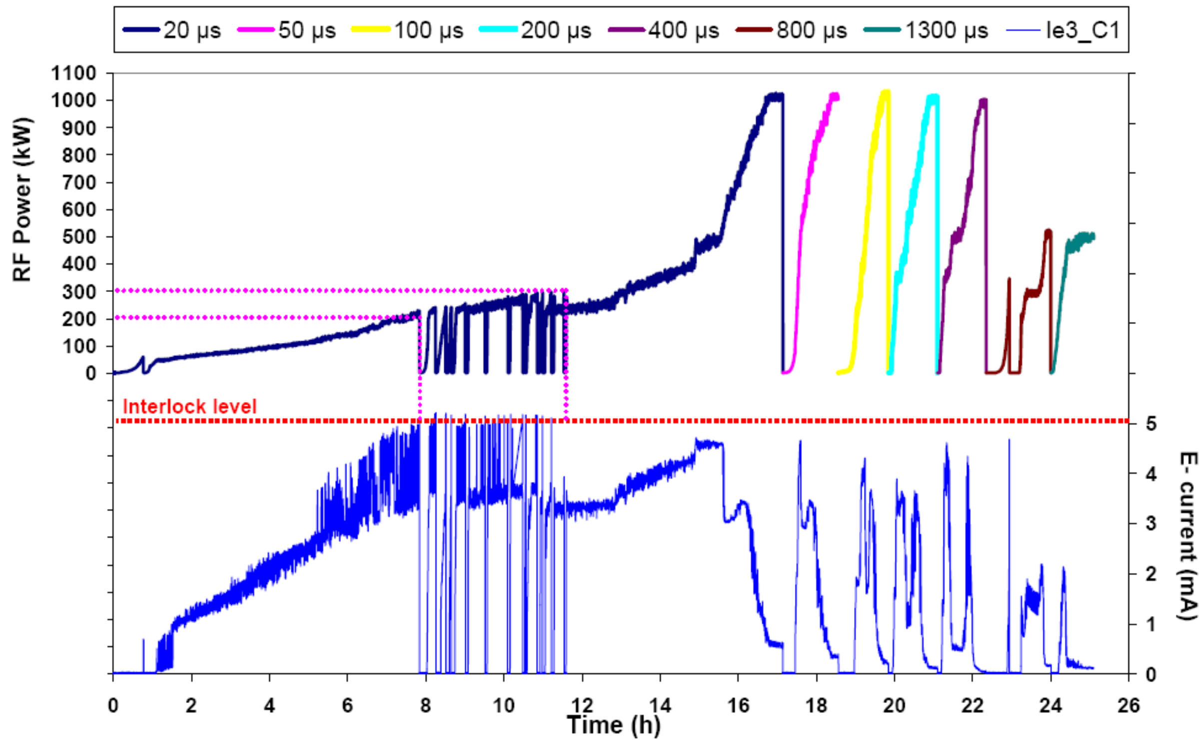


Fig. 10: Power variation during RF conditioning and interlock events. Ie3_C1 is the e⁻ current detected with the pickup of the upstream coupler cold part.

Finally, TTF-V could be conditioned in very reasonable time and we estimate that this is a very successful validation of this design. The only detail is that we expected, with this coupler design, to have less e⁻ currents in the coupler cold part. The origin of this enhanced e⁻ current should be investigated. Conditioning using 4 Hz repetition rate instead of 2 Hz could decrease the e⁻ current values before reaching 200 kW power level in order to avoid the interlocks.

As a conclusion, the two coupler prototypes TTF-V and TW60 were validated using the TTF-III RF conditioning and cleaning procedure [1]. It was demonstrated that both can reach the nominal TTF3 power with different conditioning time. This validates the RF design and the realization technology. Other measurements will be performed to understand some particular aspects of these new prototypes and to push the power range to the 2 MW range. Anyway to be used in a standard cryogenic environment some details must be improved especially to respect the thermal balance specifications.

Concerning the task 7.3 a lot of experience is been acquired working also on the conditioning of the TTFIII couplers and a strong evidence of conditioning time reduction is the result. The main activity has been resumed in the H.Jenhani document [1].

References;

1] H.Jenahni, T.Garvey and A.Variola : " RF conditioning studies of input power couplers for superconducting cavities operating in pulsed mode".
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