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# HIGH POWER COUPLERS AND PUSHING THE LIMITS OF SUPERCONDUCTIVE CAVITIES

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## *Abstract*

At present different linear accelerators (linac) projects share the application of the superconductive cavities technology. The effort on SC cavities has, in fact, pushed the cavities performances close to the theoretical field limits. A non-negligible part of this brilliant result is due to the attention paid to the integration of the cavities with their ancillaries and in particular with the interfaces. Among them a primary role is undoubtedly played by the power couplers.

The importance of the integration of the power coupler in the cavity will be illustrated. A description of the different phases needed to ensure the required high performances will be given with particular attention to the technology associated with the RF windows and their multipactor suppressing coating.

## INTRODUCTION

Over the last few years many different physics communities have shown a renewed interest in particle accelerator machines and particularly in linacs. In fact, the request for increased machine performances, as far as beam current and emittance are concerned, has to take into account the natural limitations imposed in the storage rings. For this reason new innovative concepts of linear machine are being developed worldwide. Here are some examples: the energy recovery linacs (ERL) projects, the proton-high intensity machine and, last but not least, the global collaboration that is at work to build the international linear collider (ILC), a 500 GeV electron collider for the elementary particle physics community. In these different frameworks a common element is represented by the utilisation of the superconductive accelerating cavity technology. In fact, thanks to the recent significant increase in accelerating gradient, cold technology is considered suitable for high current and high gradient accelerators.

To attain the gradient limit a SC cavity needs the strict application of an important number of preparatory steps in manufacturing and cleaning. For this reason the integration of the interfaces as the power coupler plays a fundamental role. The cold region of the power coupler has to be taken into account as a fully integrated part of the cavity itself and therefore it has to comply with the same stringent cleanliness limits and assembling procedures.

Generally a coupler can be defined as a device that transfers the power from the source to the cavity. But if its role of interface between the cavity and the "external world" is taken into account, it is easy to understand its link with the limits of the cavity performances: a perfect cavity needs a perfect coupler. In order to integrate a coupler in a SC cavity, the ultrahigh vacuum transition (from environment to the machine pressure) and the thermal transition (from ~300K to 2K) should be taken into account.

In this framework the design, construction, preparation, mounting and pre-conditioning phases are decisive for the successful operation of a coupler in a SC cavity.

## POWER COUPLER DESIGN. AN EXAMPLE:TTFIII

Different designs of power couplers have been suggested and experimentally tested on SC cavities [1]. Due to the working frequency and to the necessity of $Q_{ext}$ matching the coaxial solution is preferred to the waveguide for the SC cavities.

To better illustrate the main parts of a coupler and their function it is preferable provide a concrete example. In Fig 1 the TTFIII model is illustrated. This is the baseline solution for the future XFEL linac in DESY and for the ILC. In the design the different functions are taken into account by specific components.

The vacuum and cleanliness transition from the environment to the cavity is guaranteed by two RF ceramic windows made of Alumina. These can be cylindrical [2], planar [3], or mix the two geometries. The windows must be optimised to avoid RF reflection to the source and to minimise the secondary electron emission that can provoke detrimental multipactoring activity. This is taken into account by deposing a thin TiN film on the ceramic itself. Two transition regions are envisaged:

a) the warm part that guarantees an initial separation between the source environment temperature and pressure from the coupler one
b) the cold part that separates the coupler region integrated in the cavity from the warm part.

The thermal transition is taken into account by carefully simulating the mechanical components of the couplers and by the crucial choice of the employed materials [4]. In this context the bellows play a very important role: they compensate the thermal stresses during the thermal cycles and they act as thermal impedance between cold and warm regions. This function is very delicate since it has to fit the opposite requirements given by the static and the dynamic loads. The former demands a good thermal insulation from the environment to minimise the static power losses, the latter requires a good thermal flux evacuation towards the environment to avoid significant temperature increase (especially in the antenna and in the cold region) under RF load regime. If the dynamic losses

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are decisive in the design phase, additive thermal anchors can be added for a better heat evacuation [4].

The Qext adjustment is taken into account by designing a movable antenna [5]. Especially in this case the bellows play a major role since they must compensate the antenna movement. The mismatch due to the transient region of the RF pulse has also to be evaluated in the simulation phase.

Especially in the conditioning phase the diagnostics plays a fundamental role. Electron pick ups, photomultipliers and vacuum gauges continuously monitor the physical parameters under high power regime. A long process of optimisation of the emitted electronic currents and vacuum pressure allows for a careful processing of the couplers and for determining the correct interlocks threshold [6].

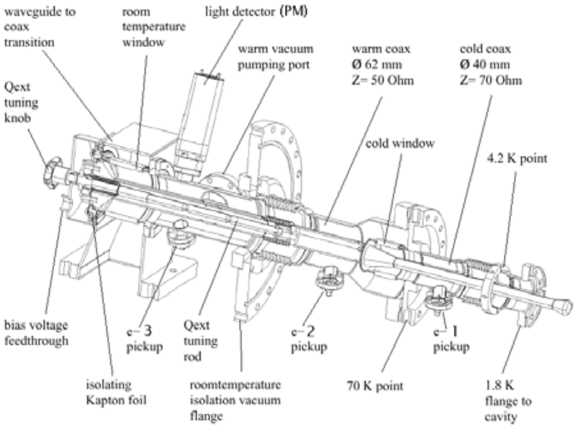

Fig.1. TTF3 power coupler design. In the figure it is possible to note the two ceramic windows, the central movable (by the tuning knob) antenna, the warm and the cold bellows and the different diagnostics ports.

## MULTIPACTOR AND COATINGS

Multipactor is a resonant physical phenomenon that severely limits the behaviours of high power RF components. Avalanches of electrons extracted from the surfaces can exponentially increase if the resonant condition is fulfilled (same impact region of the extracted electron at a integer multiple of the RF period) and if the secondary emission yield (SEY) of the surface is bigger than one. These events are characterised by some specific power thresholds. The results is a sudden and drastic increase in the electronic current that can create damaging discharges and mismatch the load causing dangerous reflected wave components to the RF source.

In power couplers the multipactor suppression is taken into account both in the design phase and in the material and technology choices.

The parameters that play a role in the design phase are the diameter of the external part, the impedance and consequently the field intensity. By varying these parameters, careful simulations must be worked out to avoid multipacting activity in the range of the coupler operation (see Fig 2).

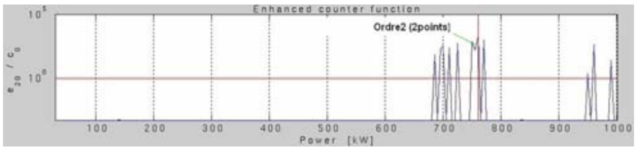

Fig 2. Example of simulated multipactor levels in a power coupler.

Very good results in reducing the multipactor on power couplers have also been obtained by biasing the central antenna. The applied voltages are of the order of few kV. When this solution is applied, the antenna has obviously to be isolated from the coupler body and the bias has to be imposed by a HV vacuum feedthrough.

Another crucial point is to identify the coupler parts that are multipactor sources owing to their surface SEY. In this context the most critical components are the Alumina RF window. Considerable effort has been made to study the SEY reduction caused by Chromium Oxide, Titanium Nitride and Titanium Oxinitrides coatings. At present the ceramic is usually coated with a thin film Titanium Nitride (TiN). This solution is preferred because of its effect on oxidation [7]. In this process particular attention has to be devoted to the impact of the coating on the window RF characteristics, namely the loss tangent and the reflected power. Different tests have to be performed to asses the right film thickness and stochiometry.

### *TiN coating techniques.*

At present two different techniques are employed to coat alumina windows with a thin TiN film : evaporation and sputtering. Excellent results have been obtained using a device exploiting titanium wires evaporation in low Ammonia pressure (99,98%) [7] (see Fig 3). A pre-vacuum of 5 $10^{-6}$ mbar is imposed before the Ti wire heating at ~ $1000^o$. After the ceramic pre heating at $150^o$ the sublimation process is started increasing the temperature up to $1500^o$. The nitrification is subsequently started after the injection of Ammonia (300 mbar per 10h). With this process an optimised film thickness from 7 to 15 nm was obtained. Thicker films show a sharp drop in the multipactor, but exhibit a too large residual conductivity.

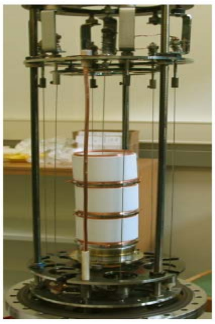

Fig 3. TiN evaporation bench. A column of three alumina windows is installed.

Magnetron sputtering has often been used in deposition of vacuum chambers to suppress the electron cloud effect. Power couplers Alumina windows have also been successfully coated [8] by DC sputtering. This was performed in a pre-vacuum atmosphere at $10^{-6}$ mbar. In this case the advantage is that the nitrification was performed in a gas mixture $Ar:N_2=1:2$ that does not have the toxic characteristics of Ammonia.

## PUSHING THE SC CAVITIES LIMITS. COUPLER INTEGRATION

As already mentioned, a SC cavity can attain its gradient limit only if perfect power coupler integration is taken into account. So, after the design phase, another important phase concerns the reception, cleaning, rinsing, baking, assembling, mounting and conditioning of the power coupler. All these steps must be carefully performed in a clean environment (clean rooms of the same class of the cavity mounting and assembling) or under laminar flow. In the cleaning and rinsing procedure it is necessary to avoid the contamination by hydrocarbons and other contaminants that can be detrimental to the superconductive state of the cavity.

There is no quantitative method or magic recipe to define a correct integration procedure. This must be implemented by an accurate optimisation of all the single steps. Different requirements and different coupler models require different recipes. To provide a concrete example we are going to describe the integration procedure always for the TTFIII model.

After reception from industry the separate parts of the coupler are mounted on an endoscope for visual inspection. The resulting photographic documentation is stored in a data base to correlate eventual conditioning problems with macroscopic defaults. After this the couplers transferred to a clean room environment. In a class 1000 clean room an ultrasound bath with detergent (3 part per cent solution) is done at a 25-40 Hz for 15 minutes. To avoid any hydrocarbon contamination by the detergent a routine of rinsing and drying is imposed. The ultra pure water rinsing is performed until the output flowing water reaches the original resistivity value of 18 MOhm cm. A similar test is imposed in the pure Nitrogen drying phase counting particles with diameter less than 0.3 microns. After the cleaning phase, a pre-baking drying is performed in a vacuum oven installed in a class 10 clean room. Eventually the coupler is assembled, vacuum sealed and transferred under a laminar flow to the conditioning area. To definitively eliminate the water vapours and other contaminants a post in-situ baking at 140 degrees is performed during 3 days.

At the end of the conditioning the coupler is stored under nitrogen (warm part) and vacuum (cold part) waiting to be mounted on a SC cavity.

The strict application of all these different procedures has given excellent results for the TESLA type cavities where gradients of more than 30 Mv/m were attained. Furthermore the analysis of the different conditioning procedures allowed reducing the RF conditioning time from ~50-90 h to less than 20h [9].

## CONCLUSIONS

Superconductive technology has drastically improved the performances of RF accelerating cavities. This opens many new prospects in a wide range of different physics communities and applications. To reach very high field gradients strict cleanliness and vacuum constraints are imposed to the cavities. In this context also power couplers play a major role. It is therefore implicit that to push the cavities limits entails a significant effort in terms of power coupler technology. In this framework the aspects related to the RF, thermal, mechanical and multipactor designs are critical. Especially the technology associated with the TiN coating of the ceramic windows is decisive in suppressing the multipacting under high power regime. Different techniques are employed but new solutions can still be explored to allow a perfect integration between couplers and cavities. It will be very interesting, in the future, to explore the possibility to integrate NEG coating in the power couplers, having so the opportunity to lower the SEY and have a local pumping effect.

## REFERENCES

[1] I.E.Campisi, “State of the Art Power Couplers for Superconducting RF Cavities”, EPAC’02, Paris, France, June 2002.

[2] T.Garvey et al. “The Tesla High Power Coupler Program at Orsay”, SFR 2003, Travemunde, Germany, September 2003.

[3] M.Stribet et al. “High Power RF tests on Fundamental Power Couplers for the SNS Project”, EPAC’02, Paris, France, June 2002.

[4] N.P Sobenin et al. “Thermal Calculations of Input Coupler for Cornell ERL Injector Cavities”, EPAC’04, Lucerne, Switzerland, July 2002.

[5] F.Krawczyk, “Interface Issues Between Superconducting Cavities and Power Couplers”. LA-UR-02-6870, Workshop on High Power Couplers, Newport News, VA, USA

[6] H.Jenhani, “Developments in Conditioning Procedures for the TTF-III Power Couplers”, EPAC’06, Edinburgh, UK, June 2006.

[7] J.Lorkiewicz et al, “Surface TiN Coating of TESLA Couplers as an Antimultipactor Remedy”,10th Int. Workshop on RF Superconductivity, Tsukuba, Japan, September 6-12, 2001

[8] T.Abe et al. “Development of RF coupler with a Coaxial Line TiN Coated against Multipactoring”, PAC’05, Knoxville, Tennessee, USA, May 2005.

[9] H.Jenhani, “Coupleurs de Puissance HF pour Cavites Supraconductrices en Mode Pulse”. PhD Thesis - LAL 06-164