PRELIMINARY DESIGN OF A 704 MHZ POWER COUPLER FOR A HIGH INTENSITY PROTON LINEAR ACCELERATOR

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Abstract

High intensity proton linear accelerator R&D program is in progress in France. The high energy part of such a linac uses superconducting accelerating cavities with two different beta sections, 0.47 and 0.65. Each cavity is fed with 704 MHz radio frequency power through one coupler. The goal is to transmit power up to at least 300 kW with a very high duty cycle (up to CW operation) and with a very high reliability. Under these conditions, RF windows are subject to thermo-mechanical stresses and potentially to multipacting discharges. The coupler design should minimize the risk of window failure and, should the window break, avoid fatal consequences for the cavity. This paper presents general design considerations, and the preliminary design of some coupler parts.

1 INTRODUCTION

High intensity proton linacs in the energy range of 0.5 to 2 GeV, have been considered for the last 10 years for a large number of potential applications, including nuclear waste transmutation, energy production, neutron sources, radioactive beams, material irradiation studies, and more recently neutrino physics. The work described in this paper was originally impulsed by nuclear waste transmutation issues [1], but is now being reoriented to satisfy several types of applications, in the framework of the new multipurpose facility now being considered at the European level [2].

This paper presents the general guidelines that we are following in the design of the power coupler. The main options that come out of these guidelines are then presented, leading to a scheme for the coupler. In a second part of the paper, RF design of individual coupler components such as RF window and waveguide to coax transition are presented. Finally, more generic R&D work on multipactor and metal-ceramic assembly is mentioned.

2 DESIGN GUIDELINES

When we first started to work on the coupler design, for the waste transmutation application, the specifications were: 300 kW of CW power at 704 MHz (matched conditions). In this power range, there are few existing examples of coupler in operation. One can only refer to Cornell CESR (261 kW, 500 MHz)[3], KEKB (380 kW, 508 MHz)[4], LEPII (120 kW, 352 MHz) [5], and a few couplers that have been tested on coupler test stands such as the LHC coupler (500 kW, 400 MHz) [6], and APT coupler (1 MW, 700 MHz) [7].

Main requirements for such a coupler are the following:

- sustain the specified traveling wave input power, whatever the conditions, to take into account the operation of the coupler with a beam current different from the nominal value (including no current at all).
- minimize the cryogenic heat loads at liquid helium temperatures.
- seal the vacuum of the superconducting cavities, while respecting tight specifications on cleanliness. Given the recent understanding on superconducting cavities performance, it is now compulsory to assemble the vacuum part of the coupler and the cavity in a clean room.
- sustain mechanical stresses induced during the cooling down of the cryostat.
- avoid multipacting phenomenon that could prevent the coupler operation at some power levels.
- pumping speed should be as high as possible to reduce conditioning time.
- minimize power reflexion at the nominal working point, to save RF power and avoid unnecessary heating of the coupler parts.
- ensure high reliability. This requirement is of paramount importance in some of the applications of high intensity power linac (e.g. waste transmutation)[8]. It has implications on the coupler and specifically on the windows, that are known to be critical components.

Given these specifications, and given existing designs mentioned above, we choose to base our design on the following philosophy:

- since the RF window is often the source of problems, having only one window should be more favorable than having two.
- in case of a window failure, the constraint of clean assembly of the cryomodule leads to a complete replacement of the entire cryostat. This operation appears to be heavy and costly in the case of frequent window failure (even if this rate is as low as once per window in the machine lifetime). We choose therefore to look at the possibility to have a valve between the cavity and the window.
- the preceding choice leads naturally to consider waveguide windows

- for the coax part of coupler, multipactor simulations favor as large as possible diameters. Moreover, simulations and experience obtained on TESLA coupler development [12] show that tapered transitions are not always good from the multipactor point of view. We decided not to consider them in our design.
- large diameters are favorable for better pumping.

3 DESIGN OVERVIEW

Following the design philosophy described earlier, our first iteration on the coupler design looks as shown on figure 1.

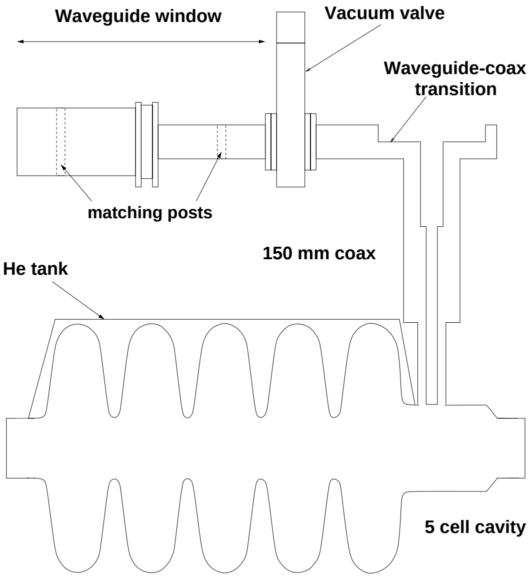

Figure 1: General coupler layout

One possible solution for th window is a scaled version of the Thomson TH25536A working at 500 MHz, that was successfully tested up to 450 kW [3, 9]. This window is expected to sustain 550 kW CW, the limitation being given by the thermal stress inside the ceramic which is conservatively taken to be less than 80 N/mm^2. An improved version based on a slightly different technology is being considered to reach a 1 MW power level.

The valve choice is not yet done: one solution which is expensive, is to design a special valve with sophisticated RF fingers. The alternative is to try to use an existing valve and modify the RF design of that region of the coupler. Both are now under consideration, but none is currently available.

Figure 2 shows a 3D view of the waveguide to coax transition, based on a reduced height WR1150 waveguide. It also displays the electric field patterns. The design was done with Agilent HFSS code [10]. The maximum field value is located on the input side of the doorknob and is about twice the field in the smaller diameter coax part of the coupler.

The coax diameter at the cavity port is fixed at 100 mm. This diameter is also the one of APT cavities, thus allowing us to test our coupler with APT cavities or vice-versa. However, multipacting considerations push towards larger diameter. Therefore, after a short length of 100 mm coax, the diameter is increased to 150 mm. The diameter transition both on outer and inner conductors is abrupt for reasons described earlier, and results in a 75 Ω 150 mm diameter matching section inbetween the two different 50 Ω lines. A multipactor simulation done with our code described in reference [11] is shown on figure 3. The 150 mm coax part of the coupler (b) is multipactor free within the specification whereas high order bands are visible in the 100 mm part (a). The barrier that occurs at 300 kW is the 8th order.

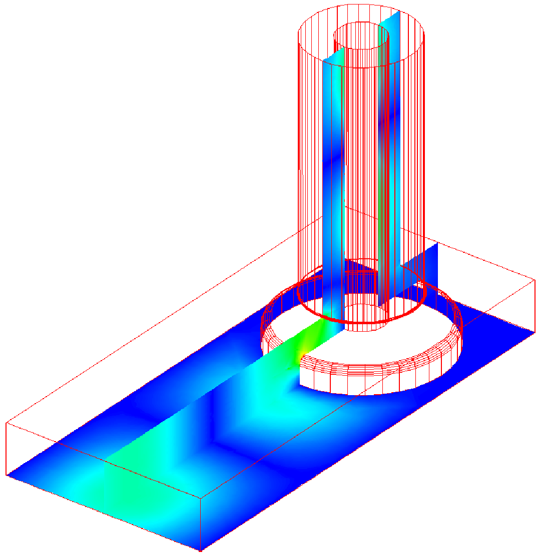

Figure 2: Waveguide to coax transition

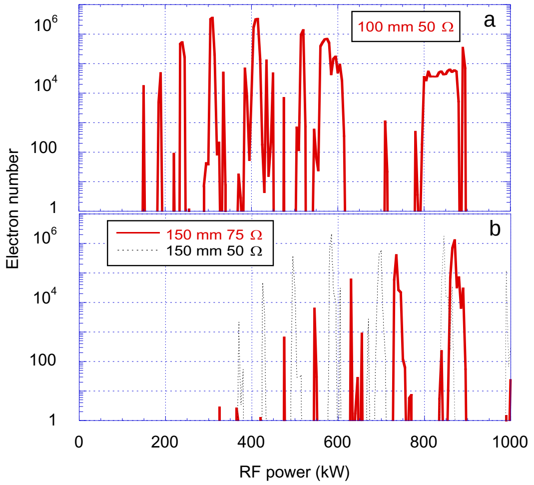

Figure 3: Multipactor barriers in the coax part of the coupler

Figure 4 shows the simulated S_{11} and S_{21}curves of the coupler from tip of antenna to waveguide to coax transition flange (waveguide side). The S_{11} is better than -55 dB at central frequency and the bandwidth is 58 MHz at a VSWR of 1.1 and still 19 MHz at VSWR of 1.01.

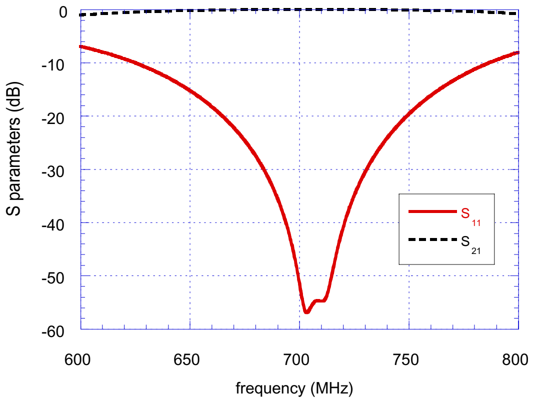

Figure 4: Calculated S parameters of the coupler

4 ALTERNATE DESIGN

An alternate design is also considered, in the case the main choices described in the previous section will meet unexpected problems.

In the case the waveguide window would not work, or in the case no appropriate solution is found for the valve, it might be interesting to consider a coaxial window. Such a window based on the traveling wave (TW) concept [13] was designed. This concept that we have already successfully tested for the TESLA coupler R&D [14], has the advantage to be multipactor free in normal matched operation. This situation results from the fact that, the standing wave pattern present on both side of the window, block the electron propagation towards the ceramic. Figure 5 shows the TW window designed for this coupler.

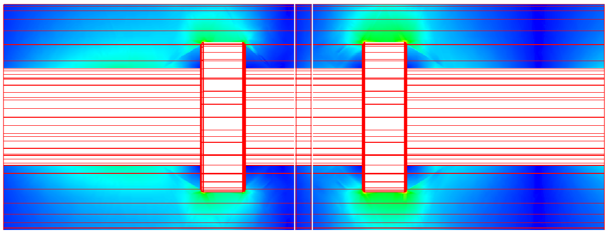

Figure 5: Traveling wave window

5 GENERIC R&D

Generic coupler R&D started within the framework of TESLA coupler [15] will be pursued. Multipactor simulations capabilities will be extended [11], and code checking with experimental results will be enforced.

RF windows commonly use metalized alumina ceramic brazed on copper or titanium. This classical method does not allow the assembly of ultra-low loss ceramic ($\tan\delta < 3 \times 10^{-5}$) which are very attractive for very high average power applications. Therefore, an R&D program has been started in collaboration with industry aiming at mastering the assembly of such ceramics on copper.

6 CONCLUSION

Based on the experience gained on our recent work for TESLA couplers, a new development program has been initiated, to develop in a 2-3 years time scale a prototype power coupler for high intensity proton linac. This coupler working at 704 MHz, should be able to handle at least 300 kW continuous RF power.

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