POWER COUPLERS DESIGN FOR THIRD HARMONIC AND SPOKE CAVITIES AT FERMILAB.

D.Arnold, T.Khabiboulline, J.Li, D.Mitchell, T.Nicol, D.Olis, N.Solyak, Fermilab, Batavia, U.S.A

W.D.Moeller, D.Kostin, DESY, Germany.

Abstract

A superconducting, 3.9 GHz, third harmonic accelerating cavity, developed at Fermilab, required a completely new main power coupler design to meet performance requirements, cost, and manufacturability. The RF design and optimization, multipactor problem analysis, and solid modeling were completed for non-adjustable version of the coupler. We have also begun a new power coupler design for the 325 MHz single, double and triple spoke cavities. The analysis of the couplers included magnetic and electrical coupling versions. In this paper, we discuss the status of the coupler development for 3.9 GHz and 325 MHz cavities .

INTRODUCTION

Fermilab is working on a few SC projects. One of them is 3rd harmonic 3.9 GHz accelerating cavity, developing for TTF/FEL facility to increase beam peak current [1-3]. Another project is Proton Driver (PD), designing to generate powerful 1GeV proton beam for neutrino physics [2]. The medium energy part of the PD linac will explore 325 MHz single, double and triple spoke SC cavities. Needed power level to feed SC cavities in both projects is from tens to hundreds of kW peak power. Since the chosen cavity frequencies are quite different from what is used in other SC projects (SNS, TESLA, etc.) none of existing power coupler can be easily adopted for projects..

COUPLER DESIGN FOR THIRD HARMONIC CAVITY

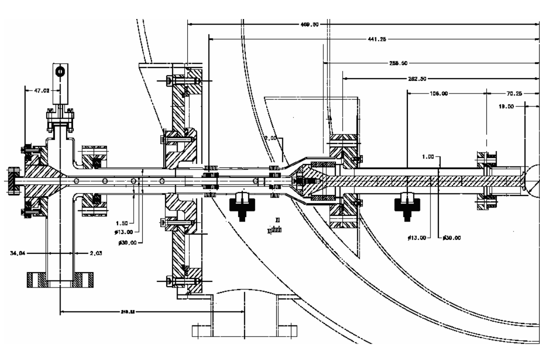

Fig. 1. Coupler layout in cryostat

The module with the four 3rd harmonic cavities is planning to install at DESY TTF/FEL facility. Since the available space is limited, the cryostat with cavities will be build as an extension of existing TTF cryostat. So, geometrical and assembly constrains for the coupler, as well as requirements are similar to the 1.3 GHz TTF coupler [5]. The required power level ~50 kW is defined by accelerating gradient 14 MV/m and beam loading. Layout of the final coupler in cryostat is shown on Fig.1. Coaxial part has 50Ω with a 30mm outer diameter to prevent excitation of the asymmetrical modes. All components of the coupler: cold and warm windows, bellow section, coax-to-waveguide transition, vacuum and diagnostic ports, were optimized by HFSS for low reflection (S11<0.05) at the operating frequency.

Windows

For the cold window we adopted cylindrical ceramic of TTF-3 coupler to reduce cost. Ceramic was supplied by DESY. The E-field distribution in cold window section and reflection coefficient vs. frequency is shown on Fig.2.

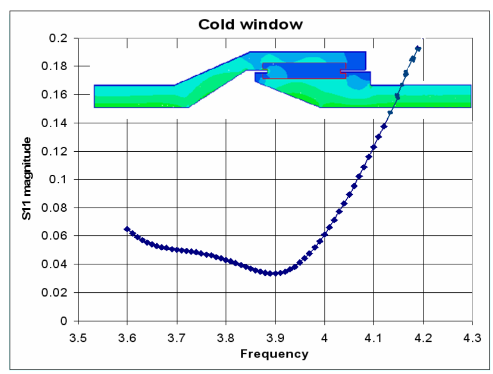

Fig.2. HFSS analysis of the cold window.

For the warm window we are using commercially available waveguide window, designed and built by CPI for the 3.9GHz 80kW klystron. Three windows were bought from company and tested at low RF power (Fig.3). In first proposal warm window was a separate piece, brazed within flange. Now it was decided to braze window in waveguide to simplify design.

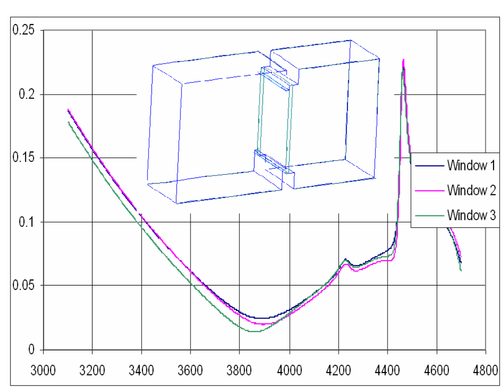

Fig.3. CPI waveguide warm window.

Coax- to- waveguide transition

Geometry of the doorknob transition and results of optimization is shown on Fig.4. Waveguide is standard copper WR284. Two big pumping ports are placed on the side wall of the waveguide. The distance between pumping ports was chosen to minimize reflection.

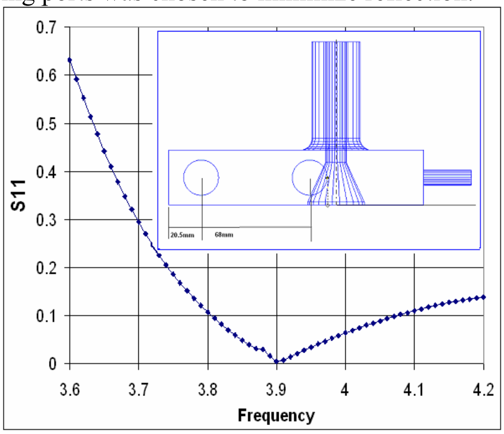

Fig.4. Coax-to-waveguide transition with pumping holes.

Bellow sections

Coupler has two bellow sections, each consist from internal and external bellows. Both are commercially available. Two bellow sections separated by 92.2 mm compensate reflection from each section. FE analysis shows that the design will accommodate forces due to shrinkage and shifting of cavity centroid during cool-down to helium temperature.

Multipactor

A lower power level and a high frequency reduce the risk of multipacting problems in the coupler. Simulations done cylindrical cold window not indicate any MP activity for the designed power level. As shown on Fig.3 multipactor in window starts at power ~10 MW. In first proposal it was planning to use DC bias, but MP calculation and DESY experience show that is not necessary.

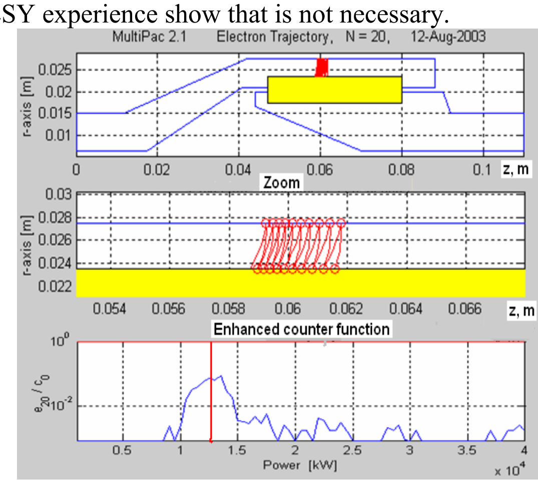

Fig.5. Multipactor calculations.

Our simulations did not show any MP activity in the coaxial part of the coupler.

Thermal calculations

Static and dynamic heating loads for copper plated and non-copper plated coaxial parts and bellows have been analyzed for the nominal RF power. Next table present maximum temperature (on bellows) and loading for non-Cu plated and 10μm platet outer conductor. Inner conductor is always plated 30μm cooper.

TTF 3.9GHz coupler: coaxial part, Cu RRR=10.

oCu	iCu	Pa[W]	Ti[K]	To[K]	P_2K	P_4K	P70K[W]
10	30	0	300	300	0.34	0.20	0.67
0	30	0	300	300	0.31	0.05	0.51
10	30	325	316	300	0.34	0.13	1.89
0	30	325	319	378	0.34	0.43	4.16

At the beginning we were planning to use adjustable design, but current design is non-adjustable. The phase and coupling reflection will be adjusted by three-stub tuner installed in waveguide.

PROTON DRIVER SPOKE CAVITY POWER COUPLER DESIGN

We also are working on power couplers of the SuperConducting Spoke cavities for proposed 8-GeV driver at FNAL [4]. The goal is to design universal coupler for of 325 MHz single (β=0.22), double (β=0.4) and triple (β=0.61) spoke cavities. RF design of the main power coupler was done by using of Ansoft HFSS software. Two types of couplers were considered: antenna coupler with electric coupling and loop coupler with magnetic coupling.

For single spoke cavity [22] the optimum position of the antenna coupler is located in plane perpendicular to spoke, where is the minimum of the surface magnetic field and strong enough electric field. Loop coupler needs magnetic field for coupling with the cavity and should be located closer to spoke basing where is the maximum of the magnetic field, fig. 21.

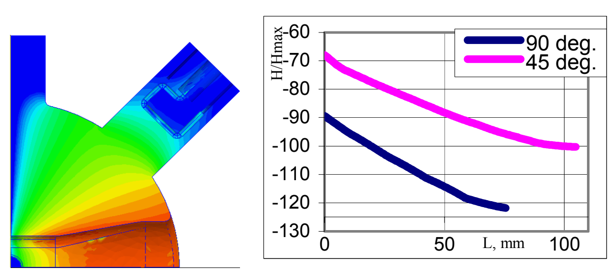

Figure 21: Left: magnetic field amplitude in mid plane of the cavity and spoke surface. Right: magnetic field attenuation in the coupler tube for 2 different angular positions of the coupler port.

In the case of coupler position 45^0 to spoke there is presence of dipole component of the magnetic field in port tube. To exclude power dissipation on normal conductive flanges, port tube length should be longer in this situation. Also we have additional power dissipation in antenna coupler tip. Loop coupler has more power losses compared with antenna coupler, for external Q of the coupler 200000 in case of single spoke cavity, 20 W and 4 W pulse power respectively.

Triple spoke cavity, as well as single spoke cavity has 3 planes of symmetry with magnetic boundary conditions. There is no magnetic field in the intersection of any 2 of these planes. So for single and triple spoke cavities an antenna coupler perpendicular to middle spoke works fine: small power dissipation on the surface of inner conductor and short port tube, fig. 22.

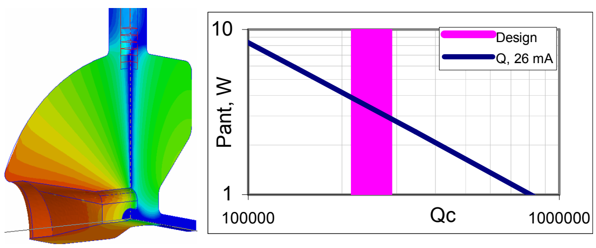

Figure 22: Left: magnetic field amplitude in 1/8 of the cavity with antenna coupler. Right: pulse power dissipation on the coupler tip vs. external Q of the coupler.

Different situation in case of double spoke cavity, where only 2 planes of symmetry with magnetic boundary conditions. Nevertheless magnetic field distribution analysis in double spoke cavity shows existence of point, on the cylindrical surface of cavity with no magnetic field (see fig. 23). Power coupler can be installed around this point.

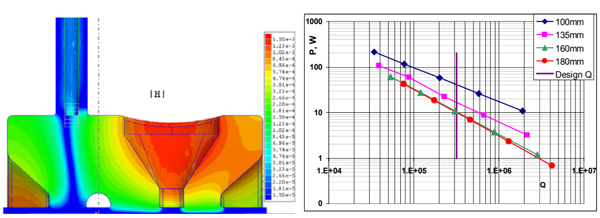

Figure 23: Left: magnetic field amplitude in double spoke cavity with antenna coupler. Right: pulse power dissipation on the coupler tip vs. external Q of the coupler at different position of the coupler.

Design of the coupler should include vacuum window to protect high vacuum in the cavity. Most part of the Proton Driver accelerator consists of ILC cavities with double window power couplers. For spoke cavity power coupler we are also planning to use two windows and as a result we have:

- Double protection of the cavity vacuum.
- Possibility of to assemble cold part of the coupler to the cavity in the very clean environment before installation of the cavity to cryomodule.

RF analysis of the vacuum window shows small reflection, fig 24. For operating frequency 325 MHz reflection from single window <0.3 and can be compensated in case of two identical windows located with interval of 188 mm.

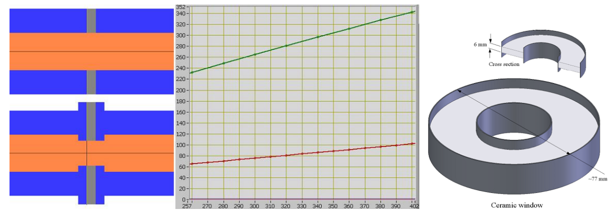

Figure 24. Reflection coefficient from single window. Green line – window without compensation and red line window with some compensation.

Mechanical design (see fig. 25), and thermal analysis started. Input flange of the coupler compatible with $3^{1}/_{8}$” coaxial cable connector.

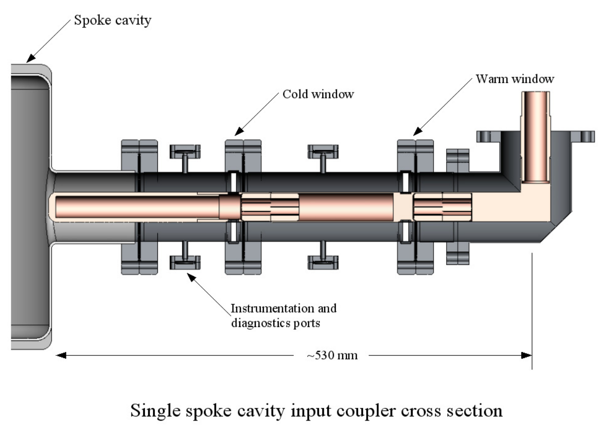

Figure 25. Mechanical design of the double window power coupler for single spoke cavity.

CONCLUSION

3.9 GHz coupler: Design is completed, windows in hand, procurements in FY2005.

325 MHz coupler: Design 50% completed, SBIR project (AMAC) with FNAL support.

REFERENCES

[1] F.Floettmann *et al.*,“Generation ultrashort electron bunches by cancellation of nonlinear distortions in the longitudinal phase space”, TESLA-FEL-01-06.

[2] N.Solyak et.al., PAC03 proceedings, pp1213-1215. http://epaper.kek.jp/p03/PAPERS/TPAB014.PDF

[3] N.Solyak et.al., Development of the Superconducting 3.9 GHz Accelerating Cavity at Fermilab, PAC2005

[4] G. W. Foster and J. A. MacLachlan, Proc. of the LINAC’02, Gyeongju, Korea, August 2002, p. 826.

[5] Dwersteg B, Kostin D, Lalayan et al, TESLA RF power couplers development at DESY, SRF2001.

[6] G. Apollinari et al., Design of 325 MHz single spoke resonator at FNAL, to be published SRF2005.