AN INTEGRATED DESIGN FOR A BETA=0.175 SPOKE RESONATOR AND ASSOCIATED POWER COUPLER*

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Abstract

Low-beta RF spoke resonators have recently been proposed for several proton linear accelerator projects. Unlike established low-beta structures such as quarterwave and split ring resonators, the mechanically more stable spoke resonators and other similar half-wave resonators have never been developed beyond proof of principle. Within the framework of the Department of Energy's Advanced Accelerator Applications Initiative (AAA) [1] spoke resonators have been proposed for the energy range between an RFQ (6.7 MeV) and β=0.48 elliptical cavities (109 MeV). To advance the understanding of spoke resonators for this application, an integrated mechanical and RF design for a β=0.175 spoke resonator with attached power coupler has been completed. The integration of the cavity and coupler was necessary due to the direct coupling of the RF power into the cavity body. In this paper the RF properties of the cavity and the power coupler are presented. Also the coupler influence on the cavity parameters and the coupling characteristics will be given.

1 INTRODUCTION

The standard procedure for the design of accelerator components is a sequential design of RF-resonators and power couplers. Modern CAD and RF-design tools allow a more integrated design of RF and structural parameters of rotationally symmetric resonators. An example is the SNS elliptical cavity design that uses an interface between Superfish and Ansys [2]. Until recently design tools allowed less integration for 3D structures. Some major 3D electromagnetic simulators now support the import of CAD (STL or SAT) models that allow RF and structural evaluation on identical geometries. Some even allow considering the interaction of RF-effects and structure deformations (e.g. for tuning).

Typically the power coupler is designed and added to the cavity to provide the correct coupling. For elliptical cavities this is appropriate, as only minor interaction needs to be considered. For spoke resonators, where the power has to be coupled directly to the cavity volume, this separation is not possible. Presented here are a combined cavity-coupler interface design, and a design of the coupler attached to this interface.

2 DESIGN TOOLS

The tasks described require a number of complimentary tools. MAFIA [3] and MWS [4] are used for the RF-properties of the spoke resonator and power coupler. All geometries have been created by Solidworks [5], a CAD modeler for the structural code COSMOS/M [6]. The 3D electromagnetic simulator MICAV [7] is compatible with the models from COSMOS/M, and permits direct study of tuning-sensitivities by deformation of the cavity end walls. The structural and thermal design of the coupler used modules from COSMOS/M. For the thermal evaluation the RF-losses from MAFIA and MWS were imported into COSMOS/M. Some aspects of the design used analytic formulas or scaling laws (e.g. multipacting).

3 RF AND MECHANICAL FEATURES OF THE SPOKE RESONATOR

Using design principles developed by Delayen and Shepard [8,9] a basic spoke resonator and stiffening layout was developed. Structural and RF-properties were optimized simultaneously. For the integration with the power coupler, the position and size of the power coupler port were selected during this step [10]. Further details of the RF-solution in the interface region were considered when the complete design was known. They provided a verification of the suitability of the interface design.

3.1 First Integration Step: RF and Structural Cavity Design

Spoke cavity designers have shown that lowest peak fields can be obtained when (1) the spoke's interfaces to the cavity wall are chosen round and fat for low peak magnetic fields, and (2) spoke aperture regions are chosen wide and flat for low peak electric fields. End wall shapes depend on structural considerations and need to provide sufficient space for the magnetic field around the spoke base. With these criteria reasonably optimized conceptual cavity designs can be achieved. For lab tests, adding the ancillary components (e.g. coupler port and pick-up port, etc.) does not alter the cavity dimensions. However, for moderate to high accelerator beam currents this design approach provides a useful but incomplete start for the final integrated cavity/coupler design. Adding these components requires dimensional changes and additional structural evaluation, thus for optimal RF- and structural performance they have to be integrated in the initial modeling stage.

3.2 Second Integration Step: Addition of the Coupler Port

Addressing this deficiency, all ports are now added to the spoke cavity model. The typically small pick-up port is a minor perturbation to the original design. However,

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power transmission and clean-room considerations dictate larger ports on the cavity. The coupler port is sized to avoid multipacting resonances in the range of operation [11]. Additionally, cryomodule assembly considerations can impact coupler location. Table 1 shows the RF-performance of the optimized spoke cavity including all ports (Figure 1) is compatible with operation on a cw proton linac with beam currents from 13 to 100 mA.

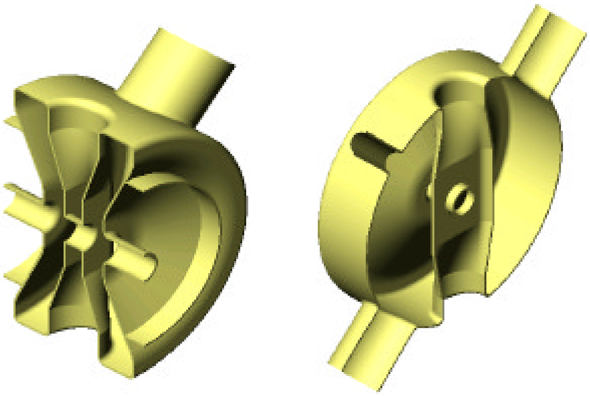

Figure 1: Two cut-away views of the optimized spoke cavity with ports and stiffening/tuning rings.

Table 1: RF Performance of the Spoke Resonator with Attached Power Coupler Port.

Q_0 (4 K)	1.05E+09 (for 61 nΩ)
T (b_g)	0.7765 (β_g=0.175)
T_{max}(b)	0.8063 (@ β=0.21)
G	64.1 Ω
E_{pk} /E_0T	2.82
H_{pk} /E_0T	73.8 G/MV/m
P_{cav} (4 K)	4.63 W @ 7.5 MV/m
R/Q	124 Ω

Figure 2 shows the structural and RF-models used for the calculation of external vacuum loads (Figure 3) and tuning sensitivities (Figure 4). The shell elements of the structural model have common interface nodes with tetrahedral elements of the RF-model. Effects of moving the end wall can be considered without re-meshing. This minimizes discretization errors, when recalculating the frequency for the modified shape. The accuracy of this implementation has been demonstrated in our RF-measurement laboratory [12]. Tables 2 and 3 show the results of these calculations for several stiffening ring positions. The impact of ring position was small over the range considered. The 26-cm diameter ring was chosen as a reasonable compromise.

Table 2: Structure with a 2-Atm Vacuum Loading

Ring - diameter	**Reaction-force [lbs]**	**Von Mises Stress [psi]**	**Df [kHz]**
28 cm	3875	5172	-94.98
26 cm	3776	5177	-87.96
24 cm	3743	5181	-74.94

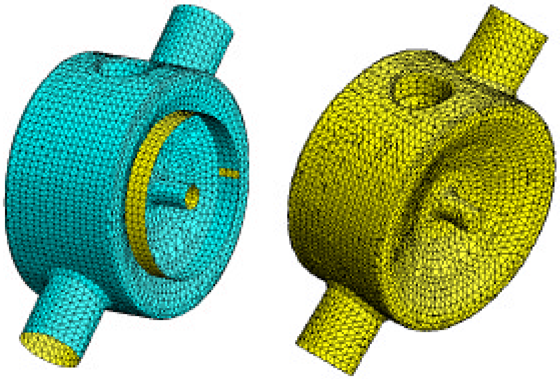

Figure 2: The shell model for structural calculations (left) and the volume mesh used for RF-calculations (right).

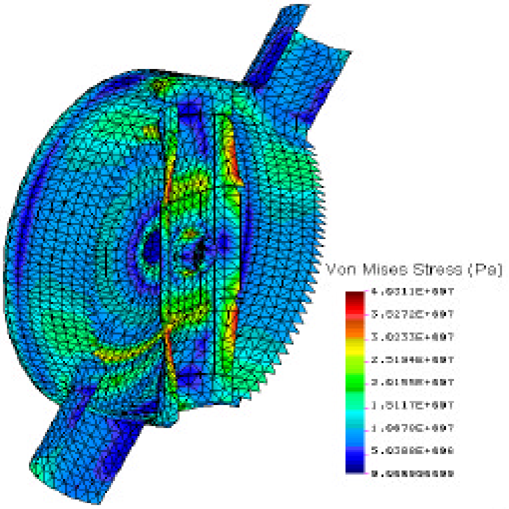

Figure 3: Stresses due to a 2-atm external vacuum load.

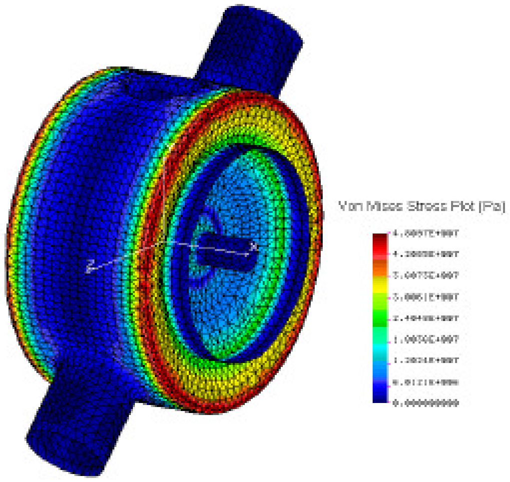

Figure 4: The stresses due to a tuning deflection.

Table 3: Tuning Sensitivity Results

Ring Diameter [cm]	**Boundary Condition**	**Tuning Sensitivity**	
		kHz/lbs	kHz/mil
28	Moving	- 0.3542	-45.148
28	Fixed	- 0.3108	-25.845
26	Moving	- 0.3914	-45.404
26	Fixed	- 0.3504	-25.664
24	Moving	- 0.4012	-46.076
24	Fixed	- 0.3490	-25.370

4 RF DESIGN OF THE POWER COUPLER

The main issue addressed during coupler design is optimal power transmission from the warm waveguide to the coaxial coupler. This can be done independent of the cavity-coupler interface [13]. Simulations have optimized the S-parameters and show the trouble-free performance of all components, such as the RF-window and the vacuum pump port. Figures 5 and 6 show a MWS model and the S-parameters for this transition. Table 4 shows selected RF-results for the coupler.

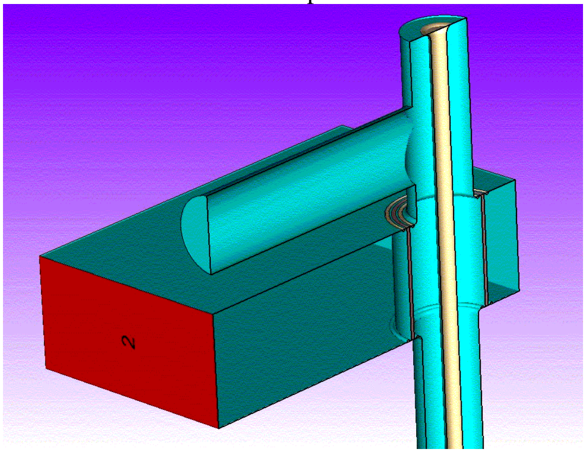

Figure 5: MWS model of the waveguide to coax transition of the coupler. The model includes a vacuum port and a realistic window-to-waveguide fixture.

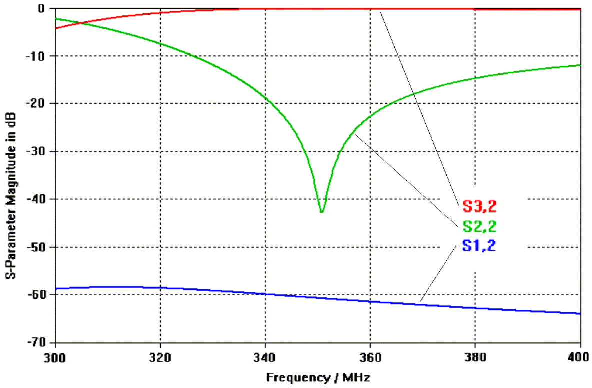

Figure 6: S-parameters for the transition. S3,2 is the transmission, S2,2 the return loss and S1,2 the transmission into the pump port.

Table 4: Selected Geometry and RF-parameters for the Optimized Spoke Resonator Coupler.

Coax short	300.0 mm to window center
Waveguide short	185 mm to window center
Vacuum port	130 mm to waveguide top
Coax-length	1191.2 mm from short to tip
Pump flange	450 mm to coax center
Orientation	45 degrees from spoke
F_{match}	349.7 MHz
S11	-56 dB (-48 dB @ 350 MHz)
Bandwidth	± 17.5 (5.5) MHz at -20 (30) dB

5 COUPLER EFFECTS ON THE SPOKE RESONATOR

Assuming electric coupling by a coaxial antenna, further simulations have been done to study (1) the coupling between the cavity and coupler, (2) the influence of the coaxial antenna on the cavity frequency (Table 5) and (3) the heat transfer from the warm antenna to the cryogenic environment. The antenna positions for a range of beam currents have been calculated by the method proposed in [14]. The frequency loading due to the coupler has been shown to be in the tuning range of the cavity. The same method has been used to construct the TW power distribution in the cavity-coupler interface region. Thermal radiation from the antenna into the cavity volume has been shown to change Q_0 of the cavity by less than 1%, even for the largest beam current.

Table 5: Q_x, Frequency Changes and Tip Positions.

I [mA]	Q_x	Df [kHz]	z [mm]
13.30	2.13E+06	reference	23
20.00	1.42E+06	-200	20
100.00	2.83E+05	-970	9

6 SUMMARY

A multi-step, integrated approach has been presented for the design of a spoke resonator and associated power coupler. Tools and methods for this task have been presented. A good understanding of the combined system has been achieved without cold modeling. The cavity and some aspects of the coupler's influence will be tested in the second half of this year under cryogenic conditions.

7 ACKNOWLEDGEMENTS

We wish to acknowledge the contribution of Richard LaFave, who implemented the interface between COSMOS/M and MICAV for the joint RF and structural analysis of the spoke cavity, before he left LANL.

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