Coupling Network Simulation for the PEP-II RF Cavity*

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Abstract

Two different input coupling networks are being proposed for the PEP-II RF cavity: a loop type and an aperture type. Both designs are expected to provide a varying coupling factor ranging from three to ten and to handle up to 500 kW of transmitted power. For beam stability reasons, it is further desirable for the coupling network to couple out any HOM's that are not adequately damped by the dedicated waveguides. This paper evaluates the coupling factors for the two types of input couplers using MAFIA, and estimates the additional damping they provide to the TM_{021} mode which has the highest residual impedance after the effect of the damping waveguides is included. Peak power densities at areas of high current concentration will also be presented.

1. INTRODUCTION

One justification for the choice of room temperature versus superconducting RF for the PEP-II cavity is based on the power handling capability of the input couplers which limits the number of cavities. Presumably it is more difficult to design a reliable high-power input coupler in a superconducting environment. This paper reports the theoretical progress made towards the design of a coupling network for the PEP-II room temperature RF system. Two different couplers are considered: a loop type and an aperture type. In section 2 the system requirements and the technical issues involved in designing each type are described. Section 3 and 4 discuss the separate numerical efforts devoted to each coupler and section 5 summarizes the current status in the evaluation of their individual performance.

2. COUPLER SPECIFICATIONS AND DESIGN ISSUES

The PEP-II coupling network is required to provide a variable coupling factor to accommodate different beam current operations. The loop coupler can achieve a coupling factor between 0 and 10 simply by rotating the loop and adjusting the loop penetration. The iris coupler, on the other hand, can vary its coupling factor between 3 and 10 through the use of quarter-wavelength transformers inserted between the coupling iris and the waveguide. The coupling network is also required to handle up to 500 kW of CW power transmitted to the cavity so thermal management of high wall dissipation is an important issue. In the loop coupler, very high surface-current can be expected so cooling channels need to be embedded in the loop, thereby making it a more complicated structure to fabricate. For the iris coupler, one finds that the junction between the coupling iris and the cavity body requires a special cooling circuit because of high power densities due to current crowding. A further specification is to consider the coupling network as part of the HOM damping scheme, so that it may couple out any HOM mode that is not adequately damped by the dedicated waveguides. Specifically, cold test results on the lower-power test cavity[1] indicate that the TM_{021} mode has the highest residual impedance and it is desirable for the input coupler to damp this mode effectively.

3. LOOP COUPLER DESIGN

A loop coupler had been used in the original PEP cavity and the same PEP loop had been tested in the lower-power test cavity setup at LBL[2]. The cold test measurements indicated strong coupling although there was some uncertainty as to whether the external circuit was matched. Recently another cold test was performed with a slightly modified PEP loop and this time a different external circuit was used to avoid mismatch[3]. The experimental data give, for a particular loop penetration, a coupling factor of 35.3 when the loop is aligned with the beam axis. When rotated 70 degrees, the coupling factor is reduced to 3.6. In the following we will describe the MAFIA[4] calculations that yield similar results. Throughout this work the cavity wall loss Q_o is assumed to be 30,000.

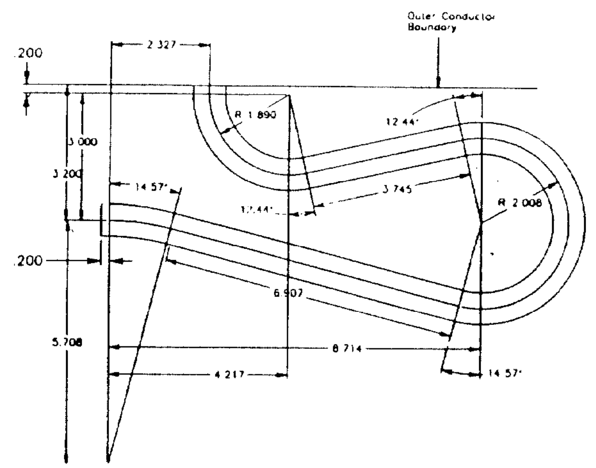


Fig. 1 The layout of the loop coupler.

The coupling loop is situated in a 6.4 in. coaxial line as shown in Fig. 1. The dimensions of this particular loop are very similar to those of the PEP loop. A 3D MAFIA model of the PEP-II cavity has been made previously for HOM damping studies. We have incorporated the loop geometry into the model and Fig. 2 shows the coupling between the cavity and the loop near the fundamental mode frequency (476 MHz) as calculated by MAFIA. In order to find the coupling factor the Q_{ext} of the whole structure (cavity plus loop) is needed. We employ the Kroll-Lin method[5] for the determination of Q_{ext} using numerical data from MAFIA simulations. The method is particularly suited for high

* Work supported by Department of Energy contracts DE-AC03-76SF00515, DE-AC03-76SF00098 and DE-FG03-93ER40759. †Also UCSD.

Q cavities and only requires two frequency-domain calculations on appropriately selected shorted lengths of the coaxial line.

For the same configuration as the experiment, we calculated a coupling factor of 34.8 with no rotation, which is in close agreement with measurement. We do not have a MAFIA model for the rotated loop, but assuming a $\cos^2\theta$ variation the coupling factor is 4.1 in fair agreement with the measured result. This approximation improves as the loop is retracted further into the coupling port as the effect of the higher order modes is reduced. In the present position the bottom of the loop is slightly over half a decay length away from the cavity-coupling junction at the fundamental mode frequency. By increasing this distance, it is conceivable that the coupling factor can be brought down to the desired range without needing large rotation to reduce the coupling. Another alternative is to change the loop geometry. The MAFIA simulations indicate that the PEP loop length is nearly resonant at the fundamental frequency which accounts for the strong coupling (see Fig. 2). We have verified this effect by substituting a shorter loop and found that the coupling factor is halved.

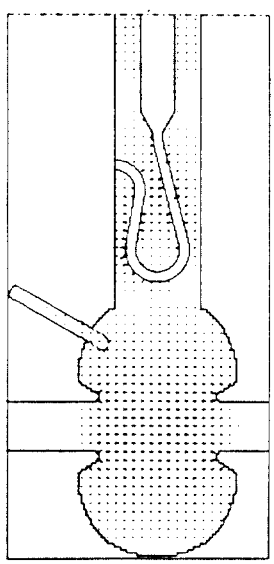


Fig. 2 Electric field of the fundamental mode with the loop coupler.

Now that we have calibrated a numerical model to the measurement, we can further use it to address the other two design issues. One is that of surface heating at high power and the other is that of TM_{021} damping. Both these problems can be studied with the time-domain module of MAFIA. In each case, a frequency domain simulation was first done to obtain the mode near its resonant frequency. The solution is then loaded as the initial conditions for the time-domain calculation. The fields in the cavity are allowed to radiate out via a matched coaxial line. For the fundamental mode the peak power density on the loop can be found by recording two field distributions at quarter period apart and calibrating the wall loss power in the cavity to the design maximum of 150 kW. Two hot spots are found: one at the bottom of the loop and the other at the end of the loop that is attached to the side wall. They are half a resonant length apart and the peak power densities are about 100 W/cm^2 at these locations.

The TM_{021} mode simulation involves monitoring of the transmitted wave amplitude in the coaxial line versus time. Then the Q_{ext} can be found from measuring the decay time constant. The Kroll-Lin method is not applicable here because single mode propagation in the radiating waveguide is assumed; at the TM_{021} frequency near 1300 MHz, both the TEM and the TE_{11} can propagate. The time-domain result gives a Q_{ext} of 740.

4. IRIS COUPLER DESIGN

The iris coupler under consideration for PEP-II has an aperture opening of 2 x 8 in. and 4 in. thickness opening into a WR1500 waveguide. In order to increase the coupling to the TM_{021} mode the aperture is displaced off center along the beam axis in the direction away from the HOM waveguides. The MAFIA model for the cavity and iris coupler configuration (with the quarter-wavelength transformer included) is shown in Fig. 3. Again using the Kroll-Lin method on MAFIA data results in a coupling factor of 3.7. By inserting a quarter-wavelength transformer 3.75 x 15 in. and 11 in. deep the coupling factor can be raised to 7.25. Hence we have demonstrated that variable coupling in the desired range is theoretically achievable by inserting exchangeable waveguide sections. In contrast to the loop coupler case, there are as yet no cold test results available for comparison.

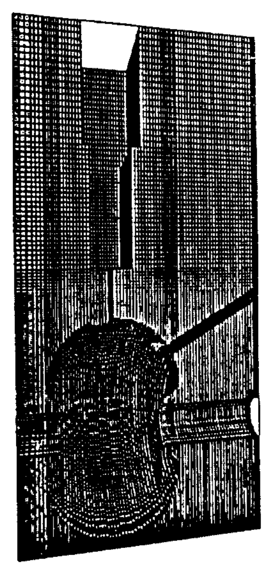


Fig. 3 MAFIA mesh for the iris coupler.

To locate regions of high current concentration and to quantify the peak power density to be expected, we follow the procedure outlined in the previous section to examine the time behavior of the fields with the iris coupler terminated in a matched load. The MAFIA results indicate that the power densities are highest around the aperture in the iris coupler assembly and the peak value is found to be 14 W/cm^2.

The time-domain simulation for the TM_{021} damping is summarized in Fig. 4. It shows the time behavior of the TE_{10} component of the outgoing wave in the WR1500 waveguide. There are four propagating modes in the guide at 1300 MHz: TE_{10}, TE_{30}, TE_{11} and TM_{11}. TE_{11} and TM_{11} are not strongly excited. The cavity was initially preloaded with the TM_{021} mode and in the early part of the decay, the cavity field retains predominantly the TM_{021} mode character as shown in Fig. 5a. At longer times, however, the cavity field is taken over by another higher order TM mode as shown in Fig. 5b. We conclude that the initially loaded field actually contains a small component of this other mode also. This is consistent with the frequency-domain results which we find the two modes to be separated by only 7 MHz. The time decay in Fig. 4 is therefore consisted of two decay times, a small one that corresponds to the TM_{021} and a large one that applies to the second higher order TM mode. We estimate the Q_{ext}'s of the two modes to be roughly 500 and 4000 respectively. Note that the HOM waveguides are left out in the simulation as the TM_{021} couples weakly to them. The other mode, however, is damped effectively by the HOM waveguides. We therefore treat the damping of each mode as the sum of two separate contributions, one due to the HOM waveguides and one due to the iris coupler. Using the measured Q of 900 with HOM waveguides and a calculated Q of 500 with the iris coupler, we obtain the combined effect on the TM_{021} mode that results in a Q_{ext} of about 300 or equivalently a reduction of three in residual impedance.

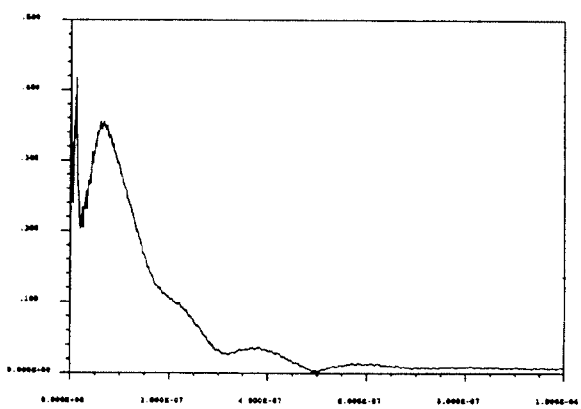
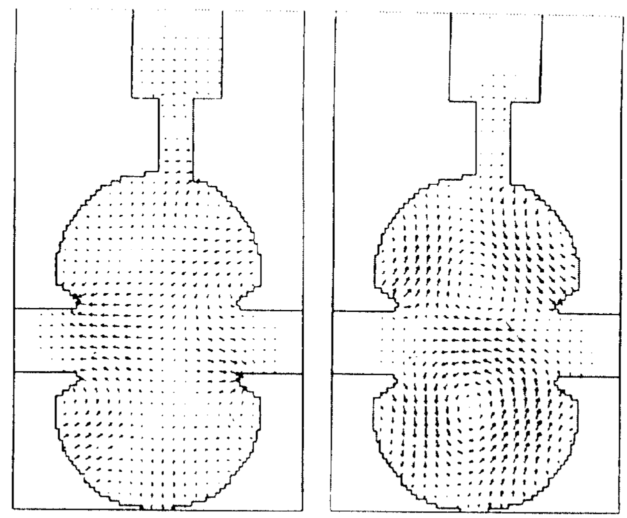


Fig. 4 Time dependence of the transmitted TE_{01} mode.

5. SUMMARY

We have described the current status of the theoretical progress made towards the analysis and design of the two types of couplers being considered for the PEP-II RF cavity. Preliminary results show that with further R & D, either coupler can be a viable candidate for final implementation into the production cavity. The deciding factor may then lie with the development of the RF window for which two options are presently being pursued: a coaxial window and a round window in a rectangular guide. The first is being developed for the 1.2 MW PEP-II klystron and is a natural choice for the loop coupler if successful. The second is intended for use in the iris coupler and is the focus of a separate PEP-II RF effort[6]. Tests on both windows are forthcoming.



(a) (b)

Fig. 5 Electric field pattern (a) dominated by TM_{021} mode at early times; (b) taken over by higher order TM mode at later times.

ACKNOWLEDGEMENTS

We would like to thank J. Judkins, R. Pendleton and H. Schwarz for useful discussions. The assistance of T. Weiland on MAFIA simulations is also acknowledged.

REFERENCES

[1] An Asymmetric B Factory, Conceptual Design Report, LBL-PUB-5379 or SLAC-418, 1993.
[2] J. Judkins, private communication.
[3] R. Pendleton and R. Rimmer, private communication.
[4] The MAFIA Collaboration, Recent Advances and Applications of the MAFIA Codes, AIP Conference Procceedings 297: Computational Accelerator Physics, p291, 1993.
[5] N. M. Kroll and X.-T. Lin, Efficient Computer Determination of the Properties of Waveguide Loaded Cavities, SLAC-PUB-5296, 1990. Computer Determination of Properties of Waveguide Loaded Cavities, Proceedings of the 1990 Linear Accelerator Conference, Albuquerque, New Mexico, Sept 10-14 1990, Los Alamos Report LA-12004-C, 238(1991)
[6] Also see M. Neubauer et. al., PEP-II B Factory Waveguide Window for the RF Cavity, these proceedings.