COUPLER DESIGN FOR NLC/JLC ACCELERATING STRUCTURES

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Abstract

In the framework of the NLC/JLC collaboration, Fermilab is working on developing the technology for X-band accelerating structures. One key element of a structure is the input/output coupler. The coupler should provide not only good power transmission from the waveguide to the structure, but also should not limit the high gradient performance of the accelerating structure itself. There are other special requirements for designing high power input/output couplers: reliability; cost; sensitivity to errors; trapped HOM; etc. In this paper we discuss the HFSS simulation of different types of couplers for JLC/NLC accelerating structures. We compare the surface electric and magnetic fields, field asymmetries, pulsed heating, presence of trapped modes and the complexity of production. Results of RF measurements and high gradient tests show good agreement with the design parameters.

INTRODUCTION

The emphasis of our present study at FNAL is on the production of two series of traveling-wave structures (FXB and FXC) required for tests at the NLCTA, the operation of the 8-Pack project, and the study of breakdown issues. The FXB structures have 60cm length, synchronous phase advance $5\pi/6$, average ratio $a/\lambda=0.18$, with an initial $v_g/c=0.03$. The FXC structures have a decreased ratio of $a/\lambda=0.17$, and all features for damping of HOM (slotted cells, HOM manifolds, etc.). Previous to FNAL's involvement in the process of conditioning the structures at SLAC, two main reasons of RF breakdown were discovered: in or near the input coupler, and the first few cells. RF breakdowns were associated with surface damage in areas of maximum surface electric field, and in areas of high magnetic field leading to plastic deformations due to pulse heating. We decided to design the FNAL structures with two different types of couplers that address the problems mentioned above instead of using the previous coupler design [1]. FXB002 and 003 used the "fat lip" coupler, a modification of the standard coupler made by rounding the coupling slot irises to minimize the surface magnetic field. For FXB004-006 and for all FXC structures, we will use waveguide couplers. This paper discusses the different aspects of coupler designs.

COMPUTATIONAL MODEL

The optimization cycle used to process each coupler design is shown in Fig.1. Solid models of different couplers are presented in Fig. 2. We match the "fat lip" coupler by varying the coupler cell diameter, the diameter of the coupler cell iris, and the width of the coupling slot. We match the waveguide coupler by varying the iris diameters of the coupler and matching cells, the coupler iris thickness, and the matching cell diameter and length.

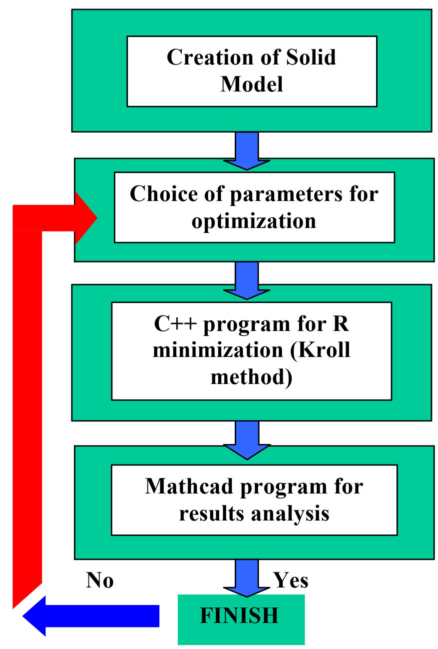


Fig.1: The optimization cycle

The main program of the optimization cycle is based on the procedure described in [2]. For each step of the cycle, the program calculates the reflection coefficient in the regular cells of the structure based upon two selected coupler parameters. Depending on the gradient direction, the program defines each parameter's new value. This procedure is iterated until the residual value of the reflection coefficient is small enough.

As well as the reflection coefficient minimization, other coupler parameters including amplitude and phase distribution, electric and magnetic surface fields should also meet the design requirements. We use a Mathcad program to help us analyze some of those requirements. If some of the parameters are unsatisfied, the computation can be restarted with new initial values.

This procedure is repeated until all of the main coupler parameters reach an acceptable range.

a.

b.

c.

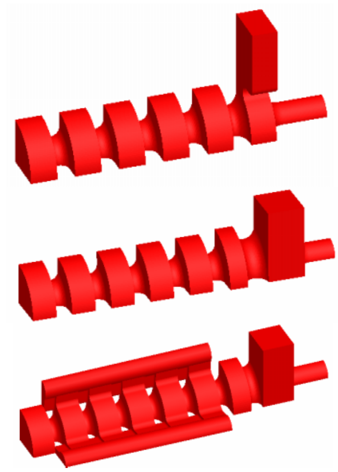


Fig.2: a. Solid model of the FXB “fat lip” coupler.
b. Solid model of the FXB waveguide coupler.
c. Solid model of the FXC waveguide coupler.

DISCUSSION OF DESIGN RESULTS

Using the procedure described above, three sets of input and output couplers for FXB and FXC structures were designed. FXB “fat lip” and waveguide couplers were produced and tuned. Designed and measured amplitudes of electric fields on the coupler’s axis and in the first few regular cells are shown in Fig.3. Good agreement between designed and measured values is shown.

The electric and magnetic fields for both kinds of couplers are shown on fig. 4. There is a difference in surface field between waveguide and “fat lip” couplers. The maximum of both electric and magnetic fields in the waveguide coupler and the matching cell are less than in regular structures. The electric and magnetic fields are about 10% and 15% lower respectively. The surface electric field in the “fat lip’ coupler can be decreased, compared with regular structures, by a proper choice of coupler dimensions. For the given design, the maximum field in a coupler cell is 10% lower. However, the surface magnetic field on the slot iris (see Fig.4 b.) is greater by about 30% than the maximum value in a regular cell.

ANSYS simulations of thermal-stresses on the coupler surfaces are presented in the table in Fig.5. The temperature and stresses are calculated for a 400 ns power pulse, for a given distribution of density of power dissipation on the surfaces (HFSS simulation).

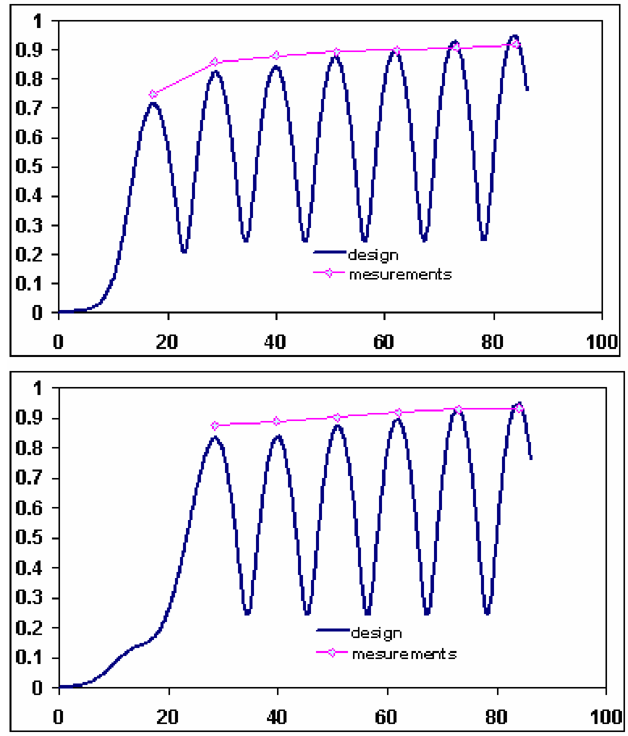
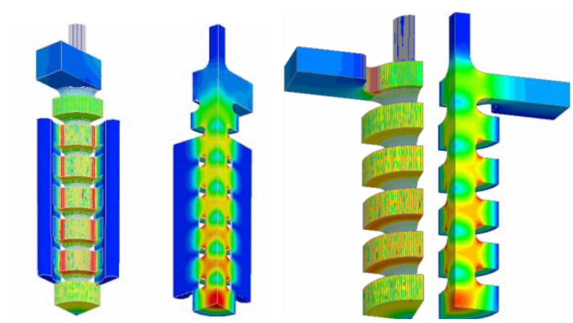


Fig.3: The designed and measured amplitude of electric field distribution for FXB “fat lip” (upper) and waveguide (lower) couplers



a.. b.

Fig. 4: Magnetic and electric fields in couplers and the first few cells.

a. FXC waveguide input coupler.
b. FXB “fat lip” input coupler.

H, A/M	P/S, VA/m**2	T, C	EQV. stress, Mpa
3.0E+5	1.26E+9	24	42
3.3E+5	1.52E+9	30	50
4.0E+5	2.23E+9	44	74
5.0E+5	3.49E+9	70	120

Fig. 5: Maximum values of temperatures and equivalent stresses for a given level of magnetic field.

For FXB structures with waveguide couplers, the maximum value of the magnetic surface field inside the regular part of structure is about $3.0*10^5$ A/m (~24°C). For FXB structures with “fat lip” couplers, the maximum value in the coupler coupling slot iris is about 30% higher, and the maximum temperature is about 40°C. For FXC structures, the magnetic field reaches a maximum value of $3.5*10^5$ A/m on the rounded coupling slots. This field level correspond to a temperature of ~34°C. For all cases the maximum value of equivalent stress is less than the yield point of copper, about (~70Mpa).

TRAPPED HOM’s IN STRUCTURES

To control multi-bunch instabilities caused by high order modes (HOM’s) in NLC accelerating structures, the design incorporates detuning as well as damping through slots into manifolds along most of the structure. One or possibly a few cells near the coupler might be uncoupled from the manifold. If for some reason, HOM’s are trapped in these uncoupled cells, the transverse wake fields compared to those in the original design can increase considerably. All coupler designs were inspected for possible trapped HOM’s. As an example, Fig.6 shows the spectrum of HOM’s for the matched FXC structure with waveguide couplers (Fig. 2c).

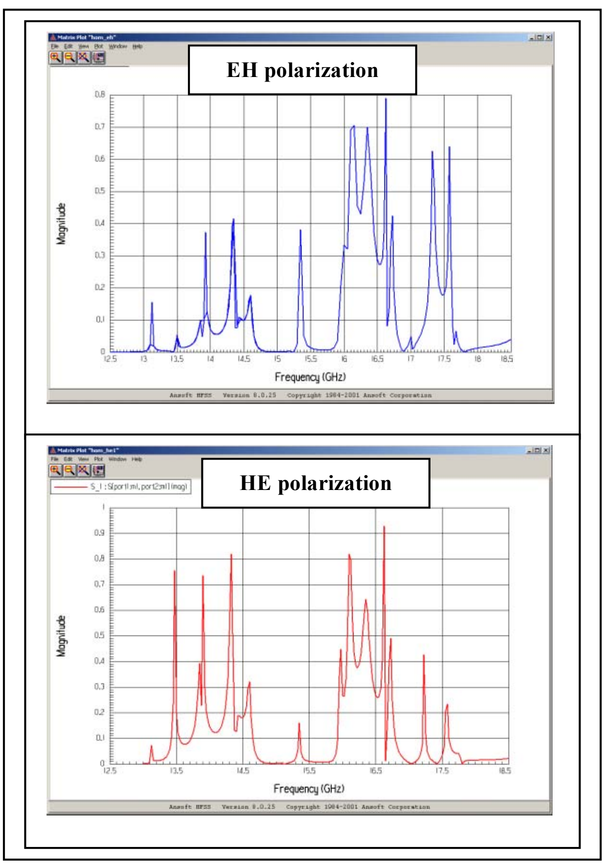


Fig. 6: HOM’s spectrums for FXC structure.

Both polarizations were studied, with EH and HE boundary conditions. For each resonance peak, the E-field pattern was investigated. We have no indication of any trapped HOM’s in this particular structure.

COUPLER PRODUCTION

All designed couplers are precision machined at Medco and LaVezzi Inc., our two major suppliers. The “fat lip” input coupler is shown in fig.7.

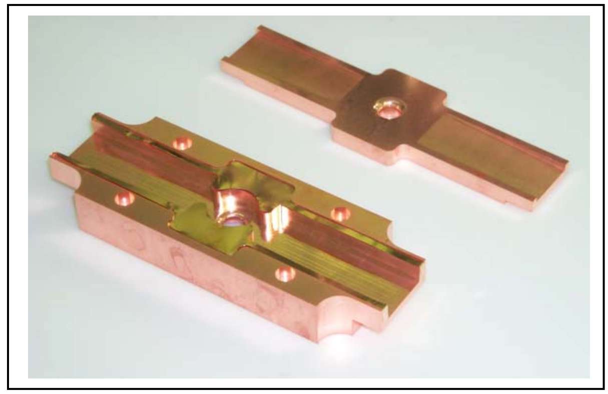


Fig. 7: “Fat lip” input coupler main body and plate.

By simplifying the design and lowering tolerance requirements, the waveguide coupler is, according to our estimation, about 25% less expensive than the “fat lip” coupler.

CONCLUSIONS

A procedure for quick and accurate coupler design is presented. Three series of couplers for structures for tests at the NLCTA were designed and produced. FXB structures with “fat lip” couplers were tuned and tested. See [3] for more details. FXB structures with waveguide couplers were tuned and will undergo high power processing in June 2003. Waveguide couplers for FXC structures have been designed.

We would like to thank V. Dolgashev (SLAC) for providing software and for useful discussions.

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[2] N.M. Kroll, et al, “Applications of time domain simulation to coupler design for periodic structures”, Proc. Linac 2000, Monterey, USA, 2000.

[3] T. Arkan, et al, “Development of X-band accelerating structures at Fermilab, PAC2003, Portland, 2003.