MEASUREMENTS OF HIGH ORDER MODES IN HIGH PHASE ADVANCE DAMPED DETUNED ACCELERATING STRUCTURE FOR NLC

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Abstract

The RF Technology Development group at Fermilab is working together with the NLC and JLC groups at SLAC and KEK on developing technology for room temperature X-band accelerating structures for a future linear collider. We have built several series of structures for high gradient tests. We have also built 150 degrees phase advance per cell, 60cm long, damped and detuned structures (HDDS or FXC series). Five of these structures have been successfully used for the 8-pack test at SLAC this summer, as part of the JLC/NLC effort to demonstrate the readiness of room temperature RF technology for a linear collider. HDSS structures are very close to the final design for the linear collider, and it was very interesting to study the properties of high order modes in the structures produced by semi-industrial methods. In this study advanced RF techniques and methods developed at Fermilab for structure low power testing and tuning have been used. The results of these measurements are presented in this paper.

INTRODUCTION

There are three basic requirements on the NLC structure design [1]: it must transfer the rf energy to the beam efficiently and demonstrate stable, long-term operation at 65-70 MV/m accelerating gradient to keep the machine cost low; it must be optimized to reduce the short-range wakefields which depend on average iris radius; and it must suppress the long-range transverse wakefield to prevent multibunch beam breakup and achieve high luminosity. During the past four years, an aggressive program has been underway by groups at SLAC, KEK and FNAL to build structures that meet the gradient requirements. Though the major emphasis has been on proving high gradient operation, an optimization of the structure for the NLC has been continuing as well, resulting in the development and adoption of a structure design (H-type Damped Detuned Structure) that basically meets performance requirements [2]. Now that significant progress in structure high gradient performance has been achieved [3], the high order modes issue must be revisited.

The NLC will require 10,000 to 20,000 accelerator structures. Each structure is comprised of about 50 accelerating cells, thus the total number of cells required is roughly one million [1]. Due to the tight tolerance requirements for these cells, quality control (QC) of RF parts is one of critical steps for this program. The full scope of QC includes many topics such as single cell and full structure QC, and RF and mechanical QC. At Fermilab, we have developed QC set-ups utilizing different microwave techniques to ensure that the machined cells are within the design tolerances, and to confirm overall RF performance of the completed structure [4]. Thus far, our routine QC procedures have not included direct control of high order modes.

The long-range dipole wakefield is suppressed in the structure design by detuning the dipole mode frequencies and damping the fields with dipole coupling channels (HOM manifolds) [2]. The dipole wakefields are the main cause of emittance increase and beam break-up in high-energy accelerators, thus understanding them is essential. Recently, we have developed methods for direct measurements of high order modes in completed structures in order to study their properties and to gain a better understanding of their relationship to single disk and full structure production.

MEASUREMENT SETUP

General

HOM measurements in a completed brazed structure requires the implementation of powerful automated bead-pull techniques. The high order modes of interest do not propagate along the axes of a tapered, detuned structure. Instead, they exist as a set of standing wave modes of different frequencies trapped in corresponding groups of cells, and it is difficult to excite and detect them in a completed brazed structure. Since the modes of interest should be coupled to the HOM manifolds and the manifolds are designed to provide good propagation for such modes, we were able to utilize the HOM manifolds for high order mode excitation and indication. For our experiments we used the FXC-001 structure (a Fermilab designation for an intermediate version of a 52 cell HDDS structure).

Simulation of Measurements

The experiments were simulated before measurements to predict what we should observe. Fig.1 shows a model of an FXC structure consisting of disks ##1,10,20,30,40,50 and 60 (there is no disk #60 in a real FXC structure, this one has extrapolated parameters). As shown in [5], a model developed with this distribution is sufficiently accurate to describe a complete tapered structure.

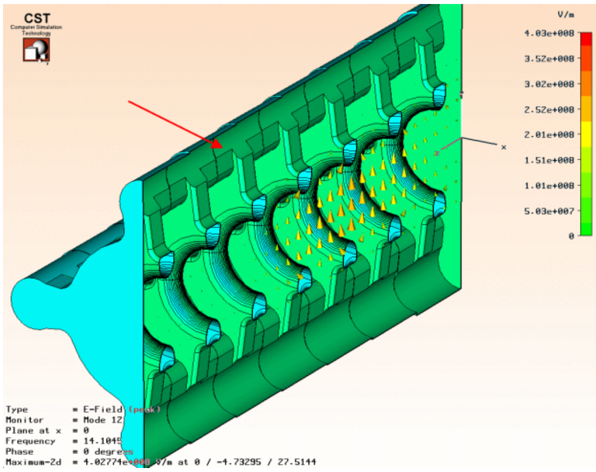

Figure 1: Distributed model of the FXC-001 structure with a simulated dipole mode trapped in the inner cells. Arrow shows HOM manifold.

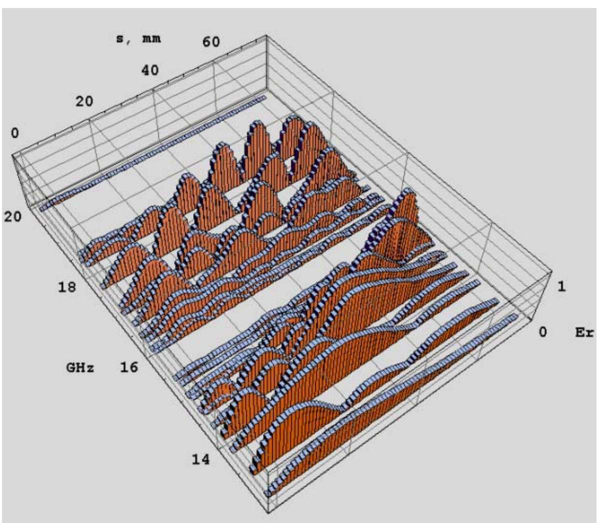

Figure 2: Distribution of E_r component of HOM field in the distributed structure model.

Fig. 2 shows the distribution of the amplitude of the radial component of the electric field along the axes for dipole modes in the 7 FXC disk stack. We referred to this data to identify numerous measured modes. Notice the clearly seen stop-band from 15.3 to 15.9 GHz, and a specific pattern of the first dipole pass-band field distribution.

FXC-001 Structure Rework

The FXC-001 structure was built for high gradient tests only, so it does not have matched HOM ports in the manifolds. Actually, the manifolds in this structure are resonant volumes rather than transmission lines. They have their own standing wave resonant modes of different field distributions. Because of this, we had to drill 12 holes in the HOM manifolds (3 holes per manifold) to position the probes (magnetic loops) so as to excite as many modes in the manifolds as possible.

Normally, HDDS structure manifolds will have matched HOM ports and stationary probes which can be used for HOM measurements, and we would be able to perform bead-pull measurements in the traveling wave regime, which is the real mode of operation.

In standing wave measurements with shorted manifolds, the HOM spectrum depends very strongly on probe locations in the manifolds. Figure 3 shows typical HOM spectra measured with probes placed in opposite manifolds at the input end, center and output end of the structure.

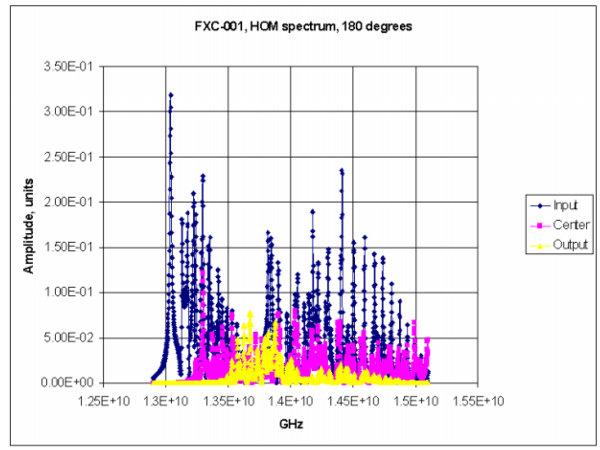

Figure 3: HOM spectra for different positions of probes.

We decided to omit measurements with the probes placed in the same manifold because we see many uninteresting modes specific to the manifold only. We also decided to omit measurements with the probes in the manifolds which are 90° apart because we observed unexpectedly strong coupling between dipole modes in orthogonal planes, and this fact requires additional consideration. Finally, we conducted measurements for different combination of loop positions in opposite manifolds.

Bead-pull Spectral Measurements

Practically, it is impossible to conduct standard bead-pull measurements of all modes seen through HOM manifolds. In order to obtain a complete picture in a reasonable period of time, we developed and applied a new method for bead-pull measurements.

In this method we first make a reference measurement of structure frequency spectra with the bead outside the structure. We then locate the bead in a structure cell, fix its position and repeat the spectra measurement. Comparison of the reference spectrum with the measured one identifies the modes that have a field in a given cell (see Fig. 4.). We then place the bead in the next cell (or next position along structure) and repeat the spectra measurements. Gradually we collect information on the HOM field distribution over a frequency interval of several GHz.

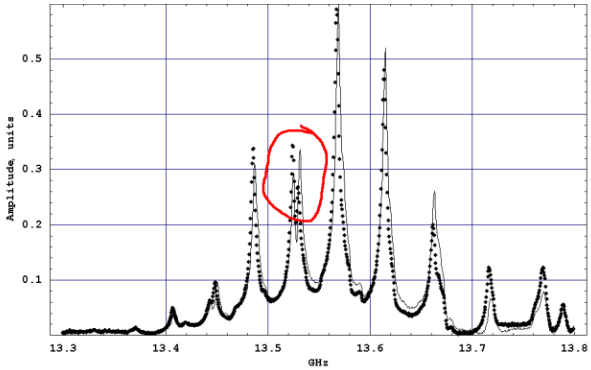

Figure 4: Large scale portions of reference spectra (solid line) and spectra taken with a bead in cell#2 (points). Comparison indicates that mode of 13.53 GHz has a field in cell #2.

We developed a special LabView program to automate the measurements – a PC controls the network analyzer and bead-pull system, and collects and preliminarily processes the stored data. Even so, the entire measurement process is still very time consuming. Depending on requirements, it takes 1-3 days to perform one run of measurements.

RESULTS

We have performed measurements for the following combination of loop positions (relative to input and output couplers): input-input, input-center, input-output, center-output, output-output. We covered the frequency range from 12.8 up to 18 GHz each run with a step of 0.5 MHz. The step for bead movement was one period of the structure for the first three trials, then reduced to ½ period for the next 5 trials. As a result, we obtained a very large amount of data and wrote several programs in Mathematica to process it.

A summarized result of the measurements is shown in Fig.5. Notice the sharp cut-off at frequencies close to the π-modes and the surprisingly long propagation of some modes along structure. The latter will probably disappear in traveling wave measurements.

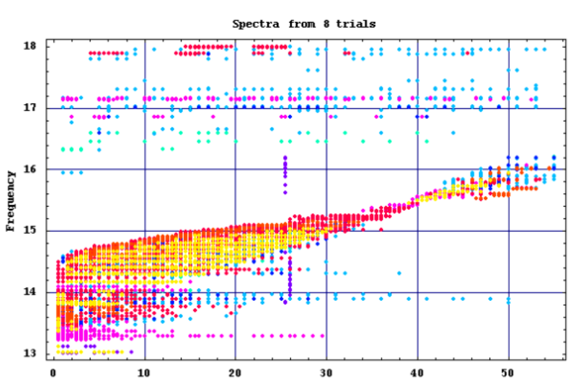

Figure 5: HOM locations in FXC-001. There are 8 separate colors in this graph, each color corresponds to a different magnetic loop positions within the manifolds.

We also conducted standard bead-pull measurements of the HOM field distribution to verify and complete the picture (see Fig.6). Detailed analysis confirmed good agreement between the two methods of measurements.

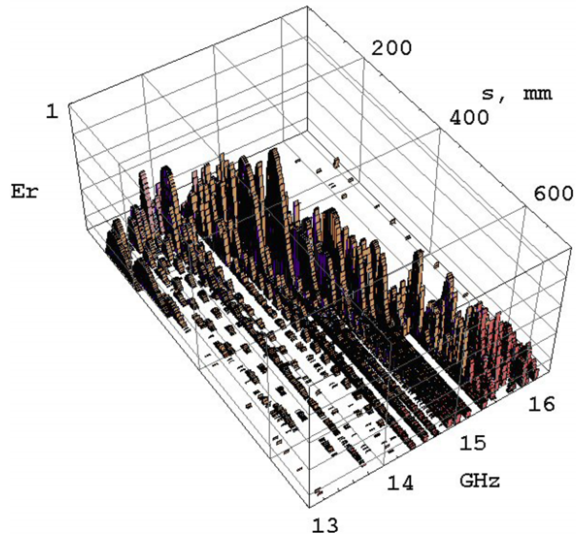

Figure 6: Distribution of E_r component of HOM field obtained with standard bead-pull measurements.

CONCLUSION

We developed bead-pull methods to measure high order modes using the HOM manifolds in a brazed HDDS-type structure. An essential part of this work was the significant expansion of the functions of our automated bead-pull system. We consider these first results very promising. We plan to modify the methods for the traveling wave case and to develop additional fast and effective QC procedures, which can be applied in industrial production flow to control HOM in completed structures.

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