MICROWAVE QUALITY ASSURANCE FOR SINGLE CELLS OF THE NEXT LINEAR COLLIDER*

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Abstract

The Next Linear Collider comprises about 5000 traveling wave sections, each manufactured from about 200 precision machined cells. Each cell in a section has a different shape. Measuring the shape of a cell with sufficient accuracy takes approximately of 1/2 hour using conventional CMM techniques. This is because many points on the interior of the cell must be measured to assure the cell will be resonant at the proper monopole (accelerating) frequency and the proper dipole frequency. On the other hand these frequencies can be measured to the required accuracy of a fraction of a megahertz in a few seconds using either a modern microwave network analyzer or a specialized system designed just for measuring these cell resonances. The microwave measurement in effect does an integral over the whole surface contour to find the net error in desired frequency. In order to avoid damaging cells it is ideal to use a non-contacting RF test apparatus with non-contacting shorts and choke joints on either side of the cell. The complex geometry of the proposed damped detuned cell structures makes it difficult to obtain high Q with non-contacting shorting plates[1]. It is still possible to get sub-megahertz resolution by measuring phase rather than amplitude at resonance and using reference cavities for calibration. It is assumed that the system will be highly automated with automatic cell handling and data recording.

Figure 1: Contacting setup.

1 INTRODUCTION

Measurement of single cell resonances is the most effective Quality Assurance test that can be made to assure that a cell has been machined correctly. In this measurement four resonances are measured: the 0 and π modes of the first monopole (accelerating) band, the π mode of the first dipole band, and the 0 mode of the second dipole band. On our last structure, the Rounded Damped Detuned Structure 1 (RDDS1) we measured every cell with two different techniques: a contacting measurement, and a non-contacting choke-joint measurement. In the contacting measurement the cell, which consists of one disk and two half cavities is clamped between two flat copper plates each with one off-center probe permitting transmission and reflection measurements of either monopole or dipole modes. The measurement apparatus is shown in Fig. 1.

Figure 2: Non-contacting setup, two chokes, monopole mode.

Figure 3: Non-contacting setup, one choke, dipole mode.

This apparatus was also used for making resonance measurements on stacks of 3n (n an integer between 1 and about 13) cells for determining the $2\pi/3$ monopole phase advance frequency directly. The non-contacting measurements were made with one apparatus for the monopole measurement, Fig. 2, and a different apparatus for the dipole measurement, Fig. 3. Each apparatus was optimized for each frequency range.

The single cell measurements will serve two primary purposes. The first is to accept or reject each cell as satisfactory for bonding in a 1.8 meter-long accelerator structure. The second is to feed corrections forward to the numerically controlled machine to keep the following machined cells centered in the tolerance band for both the monopole and dipole frequencies. A third possible use

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would be to sort the cells as to where they fall in the tolerance bands for each of the two frequencies. Using this information, a computer program would select which cells to use on each structure to optimize performance. The criterion for the monopole frequency is very different from the criteria for the dipole frequencies. For the monopole mode the average frequency of all the cells should be very close to the design and they should be distributed so that the integrated phase error to any point in the structure remains small (perhaps < 5^0). On the other hand the absolute frequency of dipole modes are not very important. Every cell in a structure has a different dipole frequency. The distribution is about 10% wide. What is important is that the density distribution of the dipole frequencies is a smooth bell shaped curve. Thus, the dipole frequency difference between each cell and its neighbors should vary smoothly.

2 CONTACTING MEASUREMENT

2.1 Concept

Clamp 1 to n cells firmly together between shorting planes and measure the frequencies of all the monopole and dipole resonant modes. The RMS scatter from smooth curve for the single cell contacting measurements for RDDS1 was 0.15 MHz for the monopole and 0.2 MHz for the dipole modes. The deviations from a smooth curve for the monopole modes of all the standard cells are shown in Fig. 4, and for the dipole modes in Fig. 5.

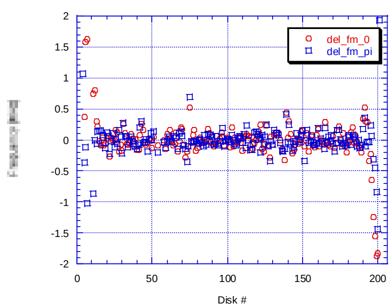

Figure 4: Contacting measurements, monopole mode.

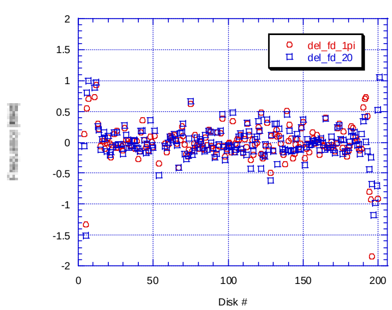

Figure 5: Contacting measurements, dipole mode.

2.2 Advantages

- Excellent reproducibility
- Can make direct measurement of $2\pi/3$ mode using 3n cells in same apparatus
- Produces details of dispersion curves necessary for the dipole wakefield analysis by looking at all of the modes in a multiple cell stack
- A single apparatus permits the measurement of the single cell monopole and dipole "0" and "π" mode frequencies for all the 200 cell types.

2.3 Disadvantages

- Damage of the disk's surface - we don't know if there is a solution for this.
- With present apparatus this method is slow - could be speeded up greatly with automation.

3 NON-CONTACTING MEASUREMENT

3.1 General

So far, none of the non-contacting apparatuses we have used has been fully satisfactory. The primary problem has been that that the choke joints radiate causing low Q. More serious is that the radiation makes the measured frequency sensitive to the external environment. The first non-contacting apparatus used at SLAC had a 200 μm gap between the shorting planes and the cell. This set up produced very low Q for the cells in the first third of the structure because the choke joint groove runs right across the center of the damping manifold in the cell. The measured frequency was very sensitive (~ 10 MHz) to the orientation of the damping manifold of the cell relative to the stainless steel posts that determine the cell position. We reduced the gaps to 100 μm and the Q improved. In the setups used for the RDDS1[2] cells the gaps were reduced to 50 μm. The monopole apparatus has a double choke-joint, with the first choke groove approximately $\lambda/4$ from the Outer Diameter (OD) of the average cavity and the second about $\lambda/2$ from the OD. The dipole apparatus has a single choke joint. It must handle more than a 10% frequency bandwidth. The RMS scatter from smooth curve is 0.22 MHz for the monopole and 0.3 MHz for the dipole. This is a combination of real machining errors and measurement errors. The deviation from a smooth curve for the monopole frequencies of all the standard cells are shown in Fig. 6, and the dipole frequencies are in Fig. 7.

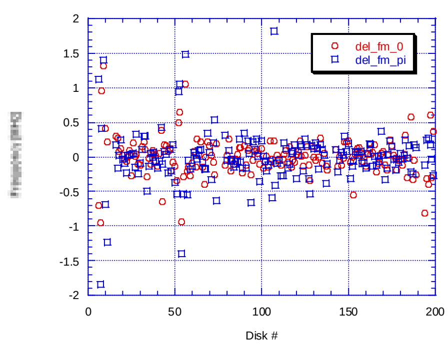

Figure 6: Non-contacting measurements, monopole mode.

3.2 Weighting Function

Weighting function is the name we have given to the function of position along the contour of the cavity which relates a unit change in the contour at each point to the resulting change in the frequency of the given mode in the cell. (Sometimes the name *sensitivity function* is used.) It

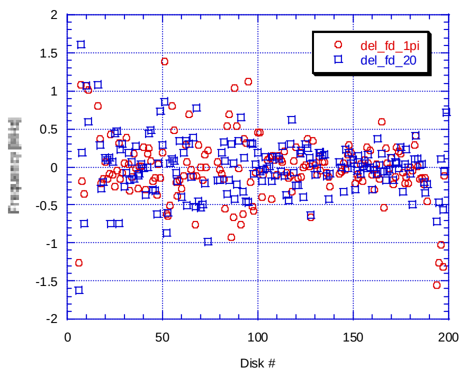

Figure 7: Non-contacting measurements, dipole mode.

is very important that the weighting function of the cell in the test apparatus be very similar to the weighting function of the cell in a periodic structure. If this is not the case there may be compensating errors in a cell which cancel each other in the test apparatus but do not cancel when the cell is used in a structure. Clearly this defeats the purpose of the test. We have modeled this numerically and the non-contacting choke test is actually quite good in this respect. The primarily effect is that scaling function is multiplied by a constant function slightly less than unity because there is energy stored in the choke joint, and the total stored energy in the cavity appears in the denominator of Slater's perturbation formula. Since this is a constant factor it does not cause the problem mentioned above. A more serious problem is that the shorting planes are part of the resonant circuit, and so if their separation is not very precisely controlled the frequency measurement will be in error. The error is of the order of 0.1 MHz per μm from plane to plane. This dimension is well determined by the cell dimensions for the clamped contacting measurement where the test is done with metal to metal contact. With the non-contacting measurement using a soft dielectric to avoid scratching the cell this dimension is less well controlled. Some of us feel that we should take a clue from the ultra-high precision lathes and use a gas bearing to set the gap between the cell and the shorting planes. If the gas used is dry nitrogen with a precisely controlled temperature, for example, and the pressure is very precisely controlled, as it must be to maintain the proper spacing, then the dielectric in the cavity is also well controlled.

3.2 Advantages of Non-contacting Measurement

- The set up for the measurement is very fast.
- Very unlikely to damage cell

3.3 *Disadvantages of Non-contacting Setup*

A. Poor long term (month-years) reproducibility resulting from the following.

- Open assembly - not easy to control pressure, humidity, and temperature which cause frequency shifts
- Dust, drops of liquid cause frequency shift.
- Soft dielectric supports wear causing frequency shifts.
- Changes in geometry due to assembling and disassembling of the apparatus.

Remedy: Avoid absolute measurements - do reference measurements with "perfect cells".

- Make a number of perfect cells so that they can be checked against each other, and so damaged or worn reference cells can be discarded.
- Make measurements of RF phase - no need for high Q
- Make reference measurements frequently - perhaps after every tenth cell in a production run of identical cells
- Make a reference measurement any time there appears to be a step function between the measured frequency and the expected frequency for the cell type measured

B. Cannot design one choke-joint stand which works well for all 204 cells.

Remedy: Reference measurements

- Several choke-stands (for example 2 or 3) can be used to cover all 200 cells
- The choke-stands are calibrated by the "perfect" cells.
- Sets of cells for each choke-stand should overlap so that a number of cells in the overlap region are measured on two different stands.

C. Cannot measure the monopole 2π/3 mode directly on a single cell measurement - can only measure "0" and "π" modes.

Solution: When you calculate the frequency of the 2π/3 mode from the measured "0" and "π" mode frequencies using the dispersion relationship you get an effective weighting function which is very close to the 2π/3 mode in a periodic structures.

4 SUMMARY

Single cell quality control can be improved by reference measurements using

- "Perfect" disks
- RF phase measurements instead of rf amplitude

The single cell measurements on RDDS1 using both contacting and non-contacting apparatuses are adequate for confirming the contours of the cells and they can surely be improved upon using the ideas presented here.

REFERENCES

[1] V. E. Balakin et al, "Fast Checking of Cells for VLEPP", LC91, Protvino, Russia, 1991.

[2] J.W. Wang, et al, TUA03, this conference