QC Needs for FXB and FXC Structures for 8 Pack Test

- What is The Goal? What is the Plan?
- (An aside on the A, B, C's of Names)
- Details: Engineering Teams and Documentation
- QC Perceived Needs and Questions

The Goal

- Fermilab's Linear Collider Goal (by Steve Holmes)

By the end of 2003, complete the R&D work leading up to CD-1.

- This means delivering twelve structures on two girders before "the end of 2003".

An aside on the A,B, C's of Names

- FXA (less than full size, high gradient test)
  - 45 mm OD, 20 cm long, simple disks for high gradient test
  - Fermilab has made one of these (FXA-001)
  - and will make two more (FXA-002 and FXA-003)

- FXB (full size, high gradient test)
  - 61 mm OD, 90 cm long, simple disks for high gradient test
  - Fermilab will make 6 of these for "Girder A" for 8 pack test

- FXC (NLC Main Linac structures)
  - 61 mm OD, 90 cm long, RDDS disks for full beam acceleration
  - Fermilab will make 6 for "Girder B" for 8 pack test

- FX = Fermilab Xband …A, B, C = Design Series

The (Fermilab) Plan for X-Band Structures

- In FY02 (with $1.95M)
  - Make FXA-002 and FXA-003 (Short ones)
    - 20 cm long, conventional machined, high gradient tests, 45 mm OD
  - Make FXB-001 thru 003 (Full length, but not yet accelerator quality)
    - 90 cm long, conventional machined, high gradient tests, 61 mm OD
    - If I have to: Use same coupler design we had in FY01 (aka “Sparky”)
    - Need to get to 1 / month <<< REQUIRES QC and QA.
  - Start on FXC (The Real Thing … No More Excuses!)
    - Final NLC Main Linac Design
    - 90 cm long, assume diamond turned, real accelerators
    - Need design (including couplers) by July 2002 (?)
    - Need to decide on bonding vs brazing (required straightness) and then learn how to do it by September 2002 (?). (Is this a sensible short term goal?)
    - Or we won’t have a prayer of making the “By the end of 2003” goal.

The (Fermilab) Plan for X-Band Structures

- In FY02 (with $1.95M)
  - Make FXA-002 and FXA-003
  - Make FXB-001 thru 003
  - Start on FXC (The Real Thing)

- In FY03 (with $x?xM)
  - Make FXB-004 thru 006 (plus two extras)
    - Assume better coupler design than we had in FY01.
  - Make FXC-001 thru 006 (plus two extras)
  - See how many we actually have in mid to late FY03 and decide what to do in FY04.

QC Needs for FXB and FXC Structures for 8 Pack Test

- What is The Goal? What is the Plan?
- (An aside on the A, B, C's of Names)
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- QC Perceived Needs and Questions

Reminder of RF Factory Elements

- Seven Elements of the RF Factory
  - RF Design
  - Produce Copper / Machine Copper
  - RF Measurements & Development / Low Power
  - Structure and Vacuum
  - Mechanical Measurements of Straightness
  - Brazing / Bonding Facility
  - High Power Processing

- The middle five elements are beginning to function.
- The Individual People are becoming a Team.

Engineering Teams

- Recently conceived (in August 2001) to help
  - focus on Technical Division FY02-03 goals for Linear Collider R&D
  - to promote better NLC R&D collaboration (particularly the Fermilab and SLAC connections)
- Almost immediately, it expanded to include
  - more than just Technical Division
  - more than just NLC R&D (includes TESLA)
- And it is a **moving target** at this time.

Aligned

For Reference …
Fermilab's Linear Collider R&D Goal (as stated by Steve Holmes):
By the end of 2003, complete the R&D work leading up to CD-1.

Engineering Teams (as of October 4, 2001). Are They the Way to Develop Specifications and QA?

For X-Band (NLC)

- **Fermilab RF Factory**
- **Structures (Mechanical)**
- **Structures (Electrical/RF)**
- **Girders**
- **Vacuum System**
- **Cooling Water System**
- **Specifications Development**
- **Quality Assurance Development**
- **8 Pack Integration**

For LC (TESLA and NLC)

- **FNAL Cleaning Facility**
- **SBIRs**
- **Permanent Magnets**
- **Demonstration of Remote Accelerator Operation**
- **Siting LC's near Fermilab**
- **Etc etc**

A Growing List

• Yes, there are names of people associated with each team and they are NOT all from Fermilab in most cases … because the world's best expertise in all these areas does not yet reside at Fermilab.

Writing It All Down.
Is this the Way to to Develop Specifications and QA?

Quality Assurance for XBand RF Structures

Draft of October 13, 2001

Brian Smith
Chris Adolphsen, David Finley, Nikolay Solyak
John Cornuelle, Harry Carter, Evgueni Borissov, Cristian Boffo
Chris Pearson, Greg Kobliska, John Carson, Tug Arkan
Juwen Wang, Ding Sun, Gennady Romanov, Ivan Gonin, Timergali Khabiboulline
Tor Raubenheimer, Leo Michelotti, Francois Ostiguy, Court Bohn
Nobu Toge et al

Abstract

Here we present the procedures to be used for X-band RF structures produced in the Fermilab RF structures factory. We present the resulting QA measurements and demonstrate the feedback of the QA measurements on the manufacture and installation of the structures.

1 Introduction

Qualification of structures requires characterization of their performace and comparison of that performance to acceptance standards.

Put Five Word Pages Here

Quality Assurance for XBand RF Structures

Draft of July 14, 2001

QC = What Are The Numbers?

- In The RF Factory …(as in any factory)

- If You Can't Write Down The Numbers,
- Then You Can't Write Down What Is Acceptable, And …
- You Can't Explain What's Needed To Those Who Will Be Making These Structures

  - And The Structures Won't Get Made "Right":
    - … According to Engineered Specifications
    - … The Same Way Six Times
    - … Fast Enough
    - … Cheap Enough

- Insert KEK report page 2 with QC and numbers

QC Needs for FXB and FXC Structures for 8 Pack Test

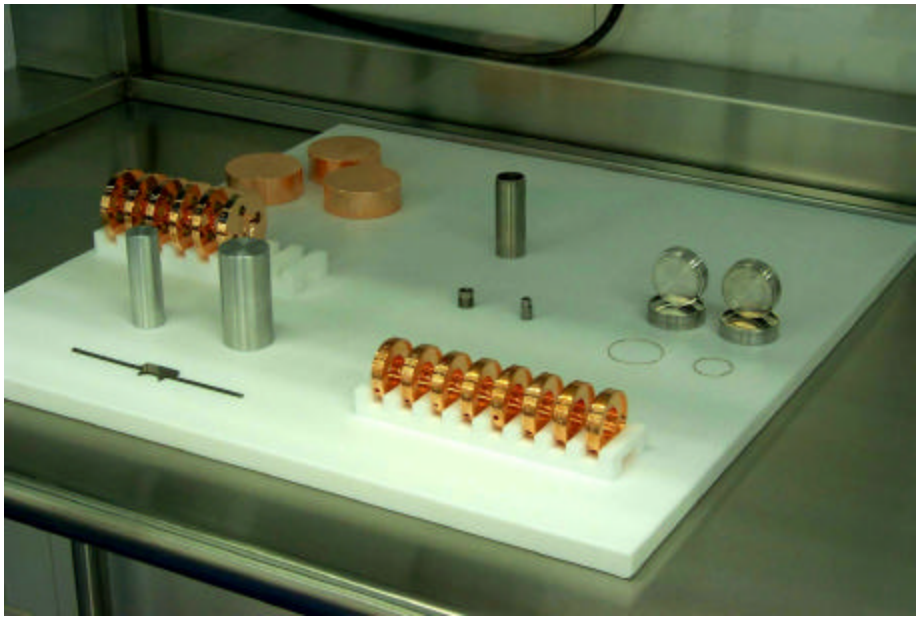
- What is The Goal? What is the Plan?
- (An aside on the A, B, C's of Names)
- Details: Engineering Teams and Documentation
- QC Perceived Needs and Questions

Are We Done With QC on Copper Materials? Probably Not? or Most Assuredly Not!

9 copper bars ~10 feet long each.

Ordered enough bars for ~10K disks (~100 meters total).

Parts machined in US industries.



Have made both RDDS diamond turned disks, and conventional machined high gradient test disks.

ETF needed ~5K disks.

Eight Pack Test needs ~1K disks.

NLC needs ~1M disks (for 500 GeV center of mass.)

Mechanical QC on Parts.

Do we need to do Mechanical QC on parts and sub-assemblies?

Can we use our present CMM equipment?

Can we use our present CMM's on the rf surfaces of FXBs?

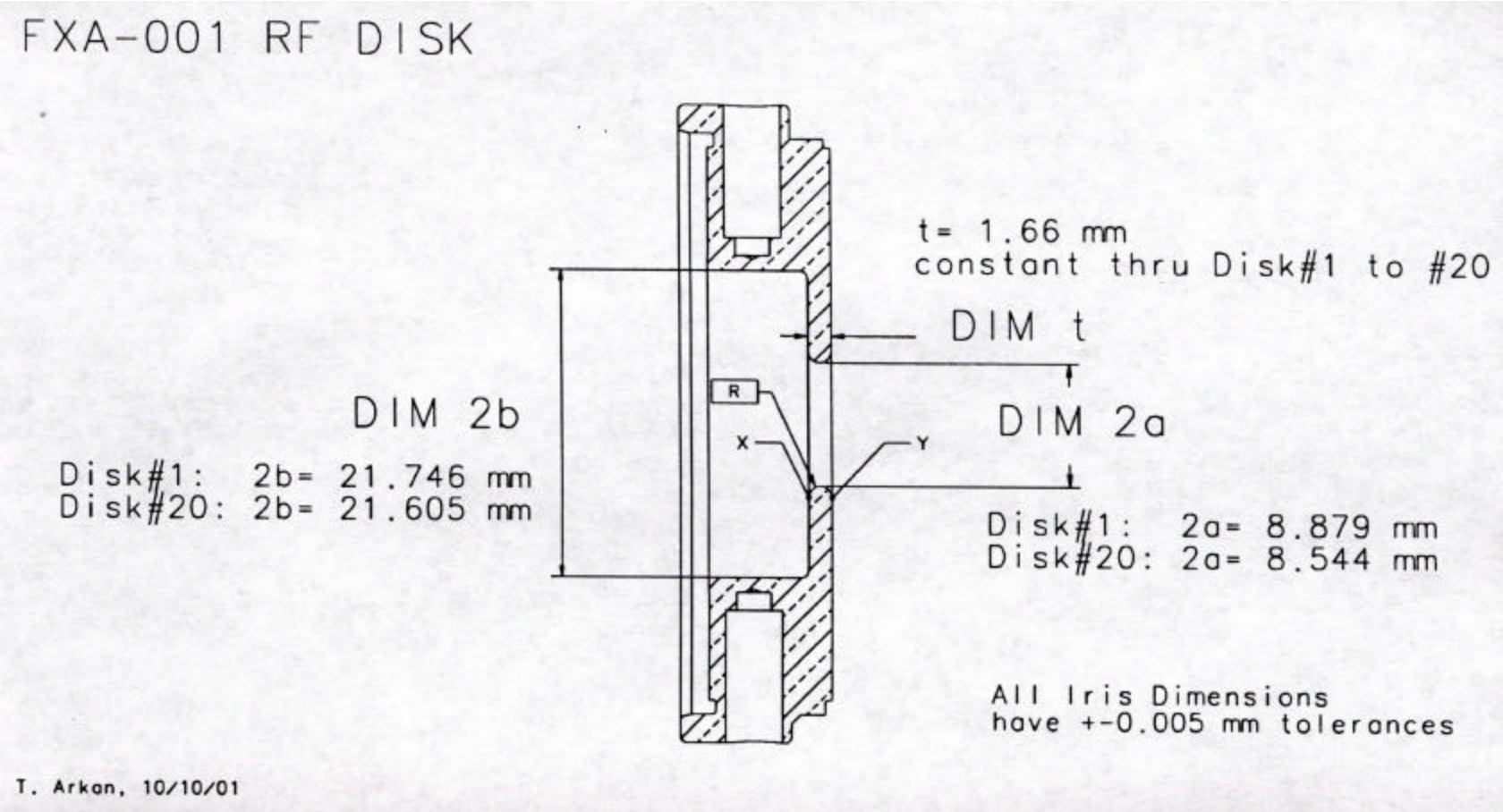
Do we assume we cannot use our present CMMs's on the rf surfaces of FXCs?

Or do we need to do QC on "test samples" of parts?

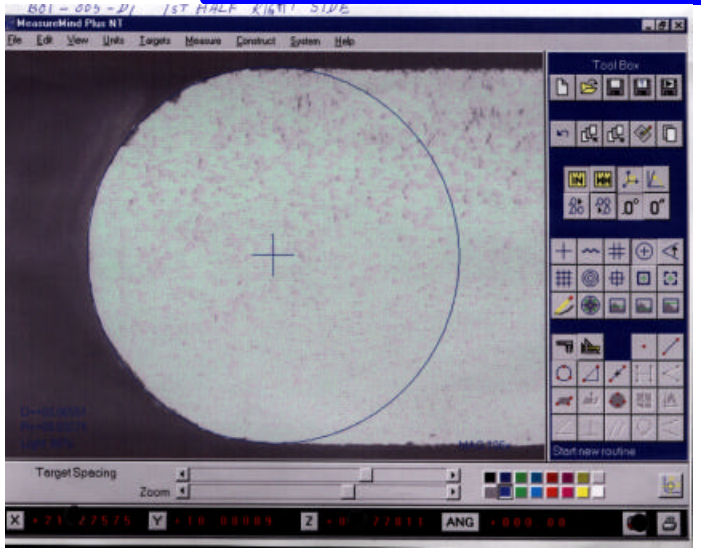
Do we cut apart "test samples" and look at the irises or do we spend at least $1M on better equipment?

FXA-001 Disk Specifications

- 2a, 2b, thickness, (length), and round iris.

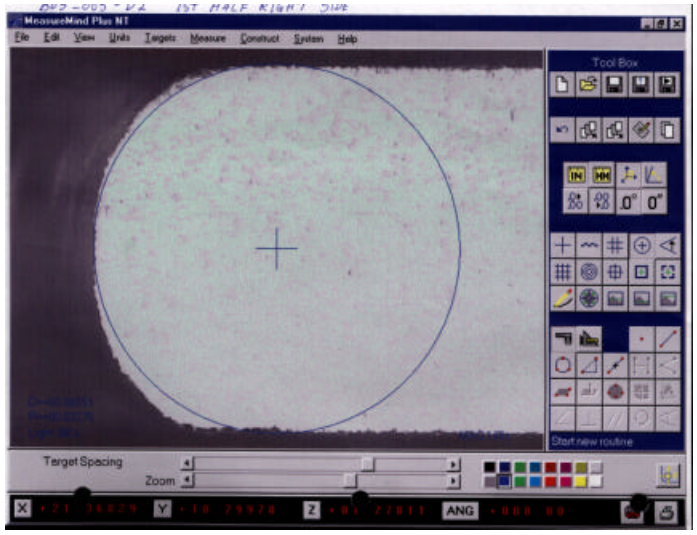


A Lesson From FXA-001: It's not just 2a, 2b and thickness



Vendor #1 looks "good" here.

… but would not pass single disk RF QC due to large disk to disk variations.



Vendor #2 looks "not good" here.

… but single disk RF QC showed very good disk to disk control.

Single Disk Mechanical QC: Questions on Zygo and Zeiss

- Do we need Zygo?

Zygo machine costs ~$400K.

Not going to buy Zygo machine until we know we are doing diffusion bonding rather than brazing.

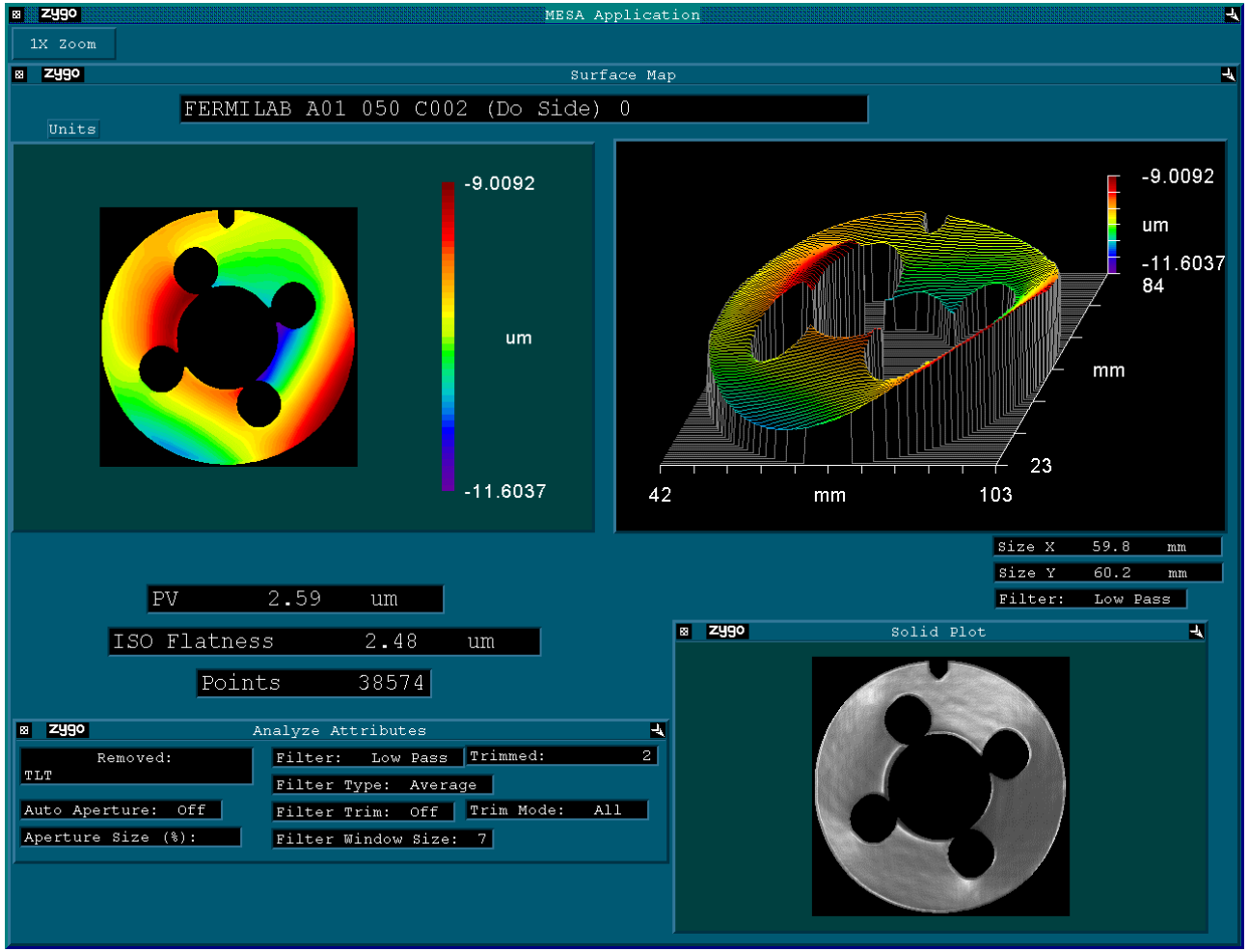
- Do we need Zeiss?

Zeiss machine costs ~$500K.

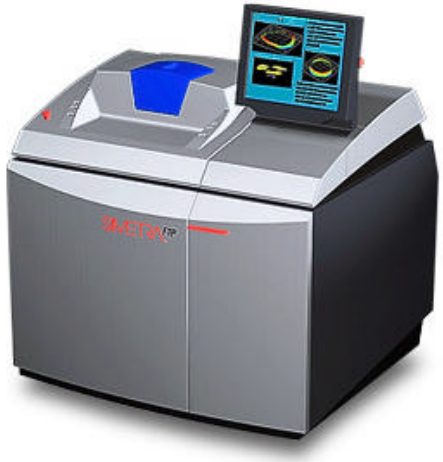
Might (or might not) buy Zeiss machine because it is a general purpose light touch 3D coordinate measuring machine.

Mechanical Measurements of Flatness of RDDS Disks (Tug Arkan, Gregg Kobliska & Co.)

Zygo machine measures flatness well enough.



Zygo machine costs ~$400K.



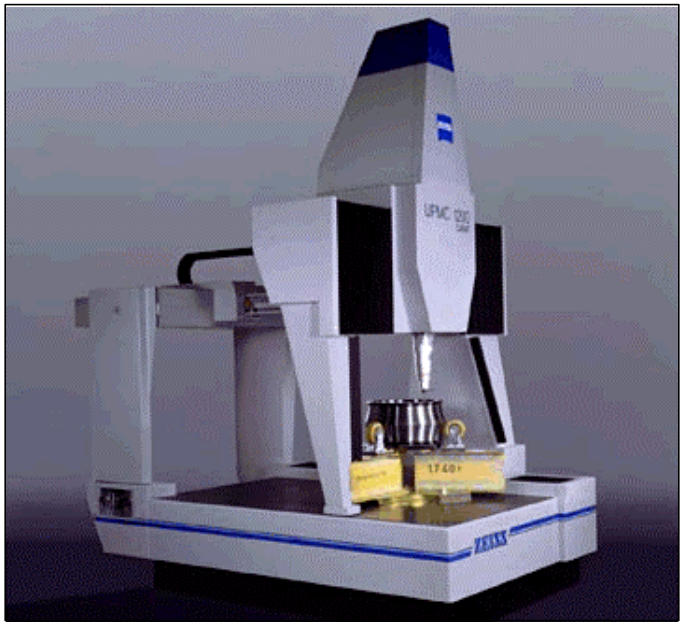
Not going to buy Zygo machine until we know we are doing diffusion bonding rather than brazing.

Mechanical Measurements of RDDS Profiles (Tug Arkan, Gregg Kobliska & Co.)

Measured four profiles along the tear-drop shaped iris of the rf surfaces of six RDDS disks.

Results reported in D. Sun et al PAC01.

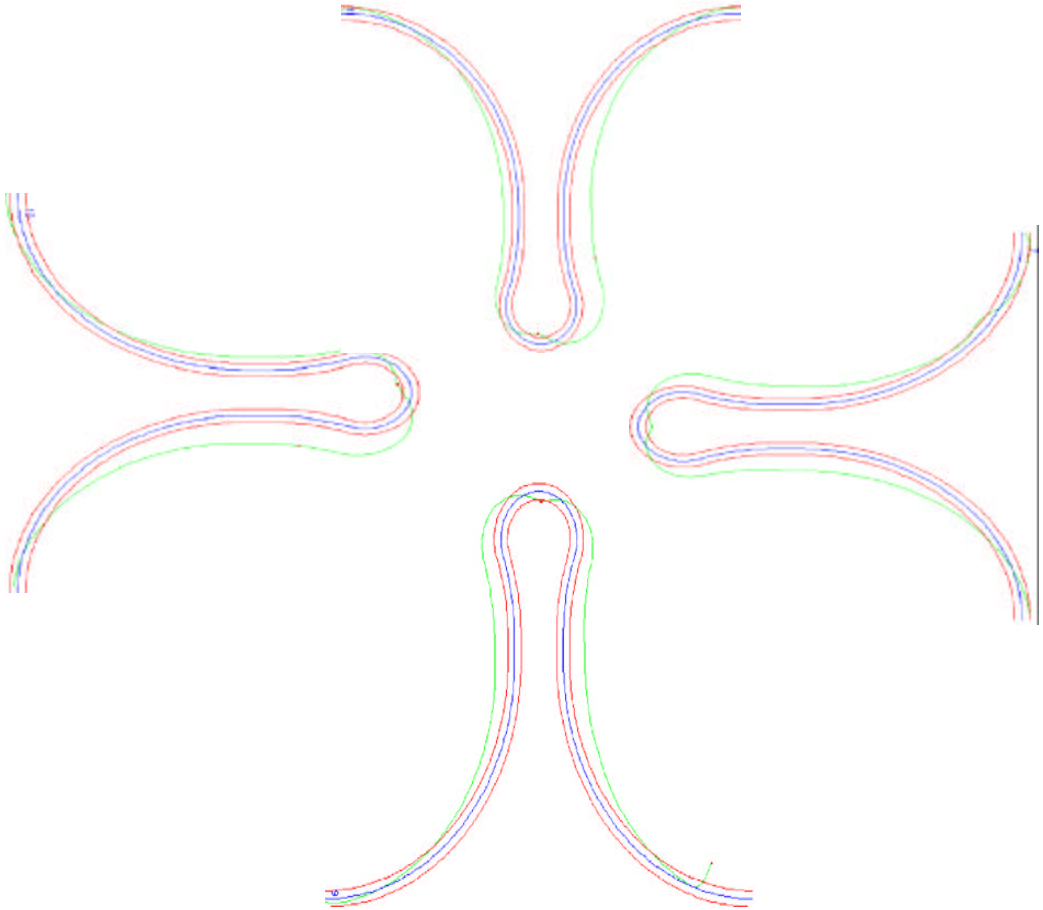
Zeiss machine costs ~$500K.



Might (or might not) buy Zeiss machine because it is a general purpose light touch 3D coordinate measuring machine.

Mechanical Measurements of RDDS Profiles

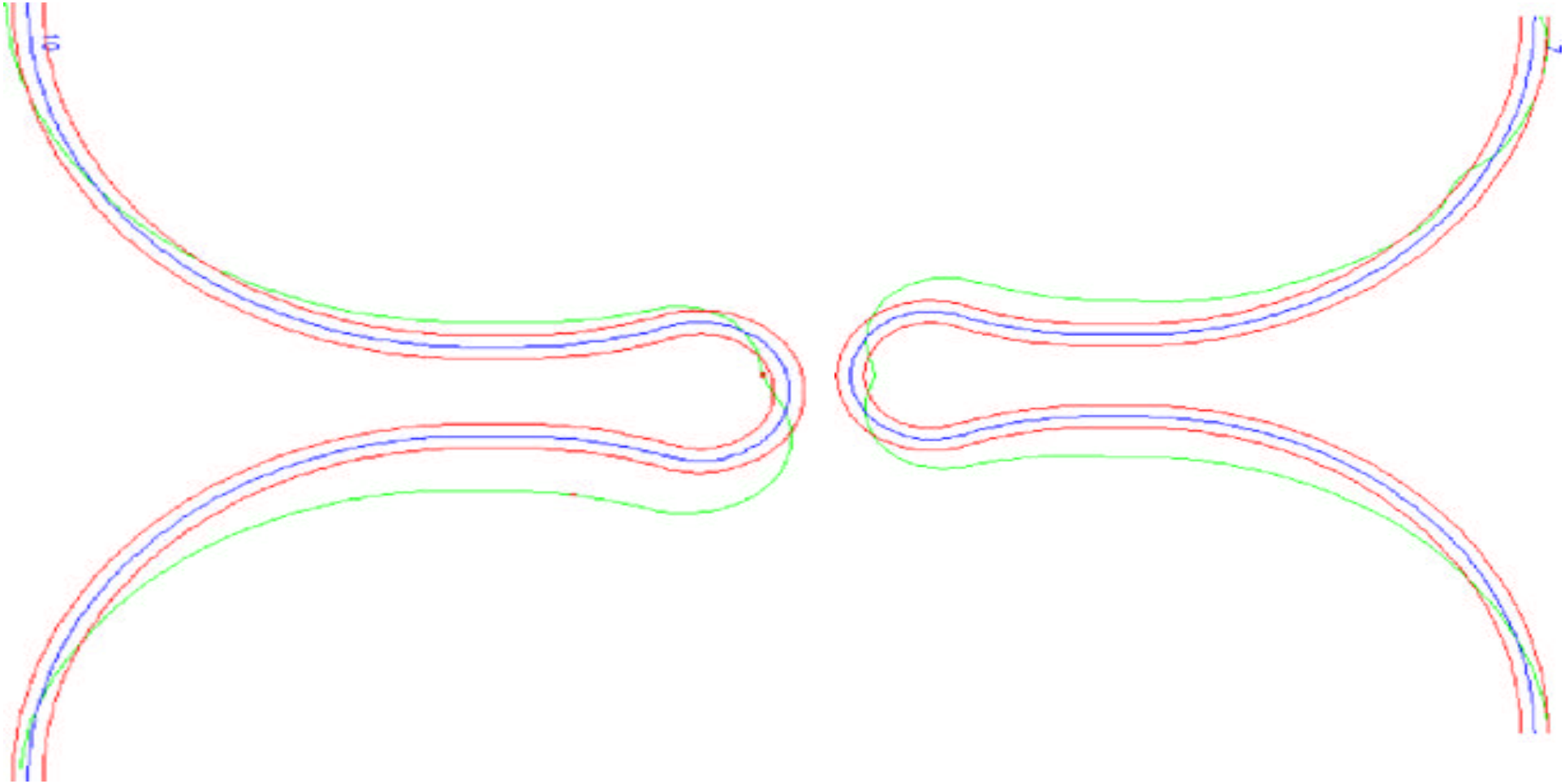
Four measured profiles (see below) along the tear-drop shaped iris of the rf surfaces for one RDDS disk.



Contours of RDDS disk # C001 taken from D. Sun et al PAC01. (1 of 6 disks.) green: measured, blue: design, red: tolerance (+- 1 micron)

Note: The four measured shapes are artificially displaced toward the beam line for clarity of presentation.

(Not Necessarily to Scale) Blown Up RDDS Profiles



How Clean Do Our Furnaces Have To Be?

- The small furnace in place in IB4.

- Will be for bonding and brazing studies.
- Will be used to make X-Band sub-assemblies.
- Will likely also be used for electron cooling and maybe scrf.
- Need full sized furnace for final X-Band assemblies. (March 2002.)

How Clean Do Our Clean Rooms Have To Be?

On a good day

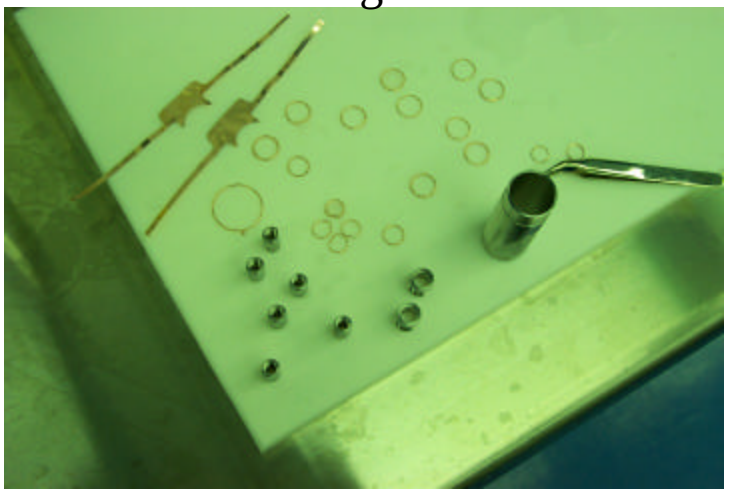
Clean Room A is Class 2000

Clean Room B is Class 1000

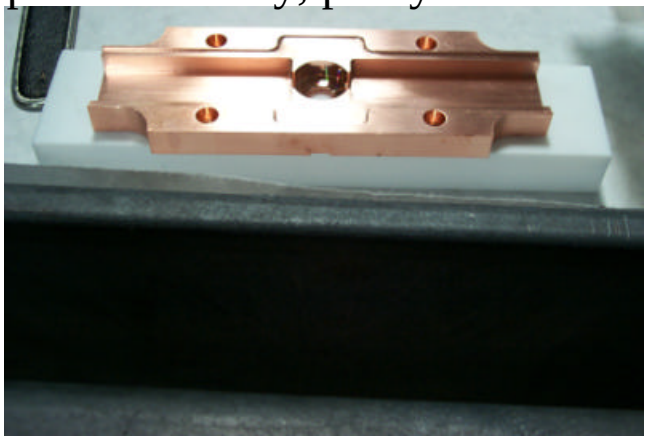
And Class 10 in the “hood”

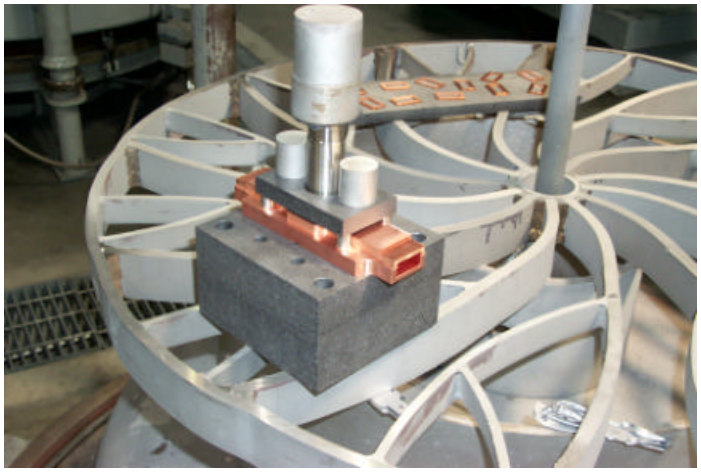
How Clean Do Parts and Sub Assemblies Need To Be? Couplers, Disks, Brazing Materials for FXA-001

Some brazing materials etc.

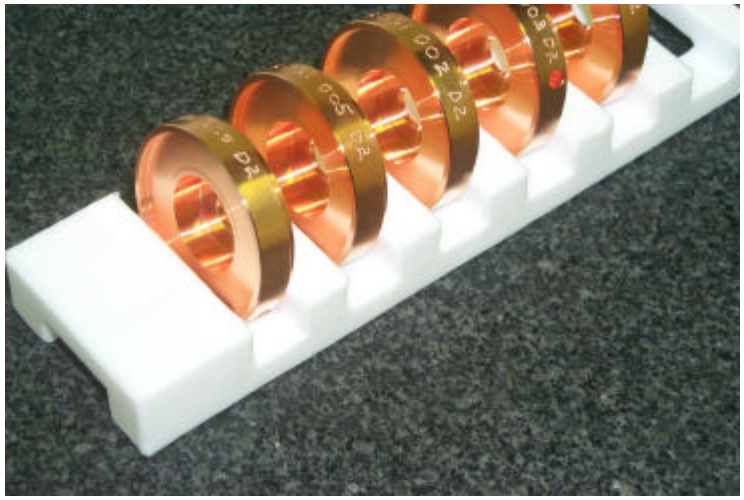


Coupler main body, partly diamond turned.





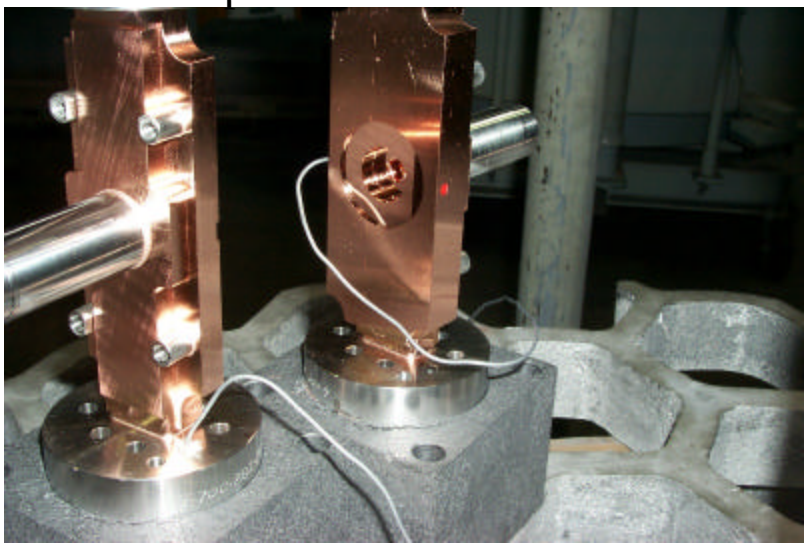
Coupler and beam tube subassembly.



45 mm OD disks for high gradient tests

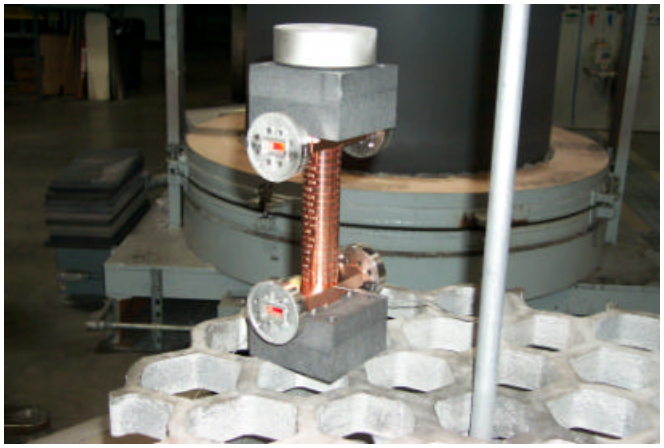
How Clean Do Sub Assemblies Need To Be Kept?
FXA-001 Sub-Assemblies at Alpha Braze (Fresno, CA)

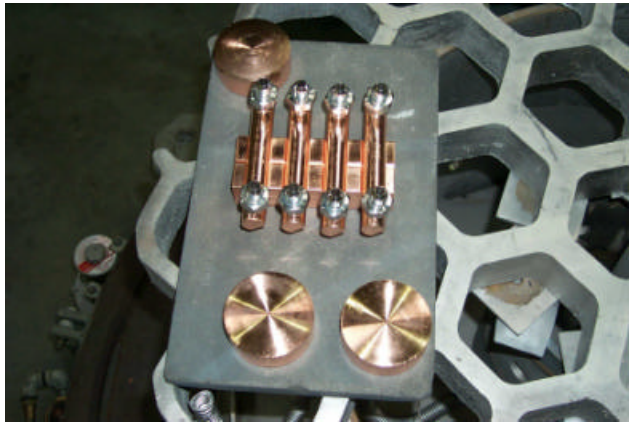
Both Couplers with beam tubes.



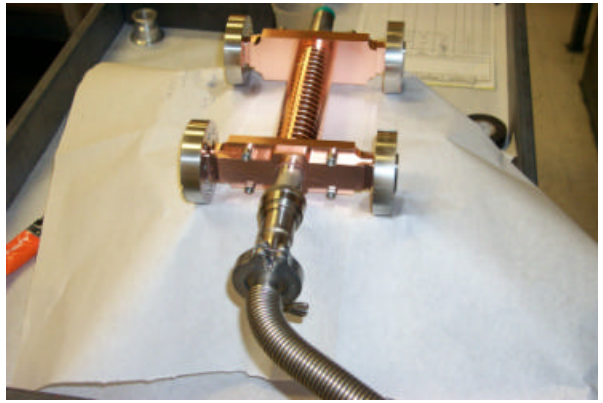
<<< Note mirror quality rf surfaces provided by diamond turning machining.

Couplers and disks.



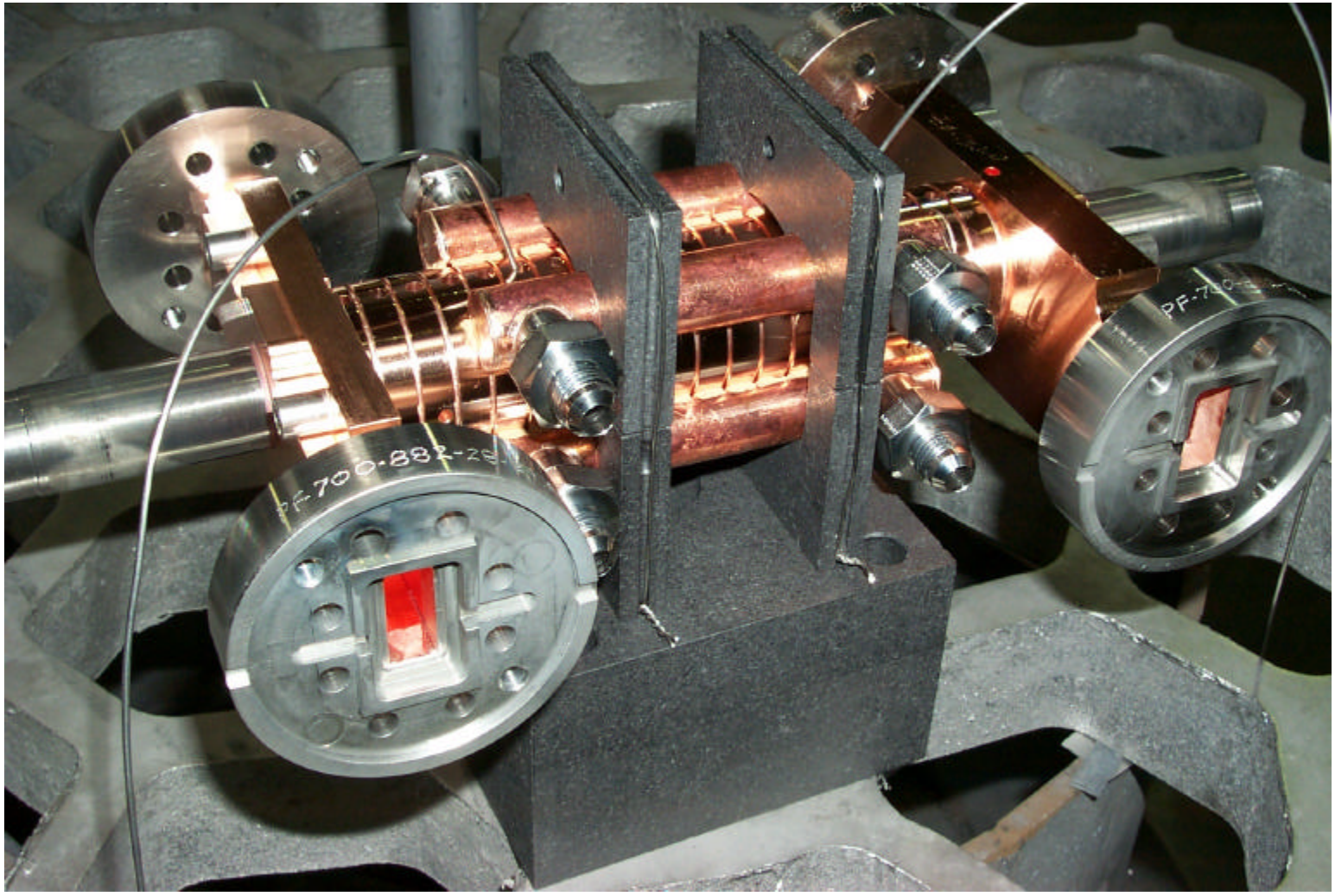


Cooling water tubes and test blocks.



Leak Check.

How Clean Does The Final Braze Need To Be?
FXA-001 Final Assembly at Alpha Braze (Fresno, CA)



Straightness QC.

Is the Way we Measured Straightness on FXA-001 Good Enough with our existing equipment?

What straightness does FXB demand?

What straightness does FXC demand?

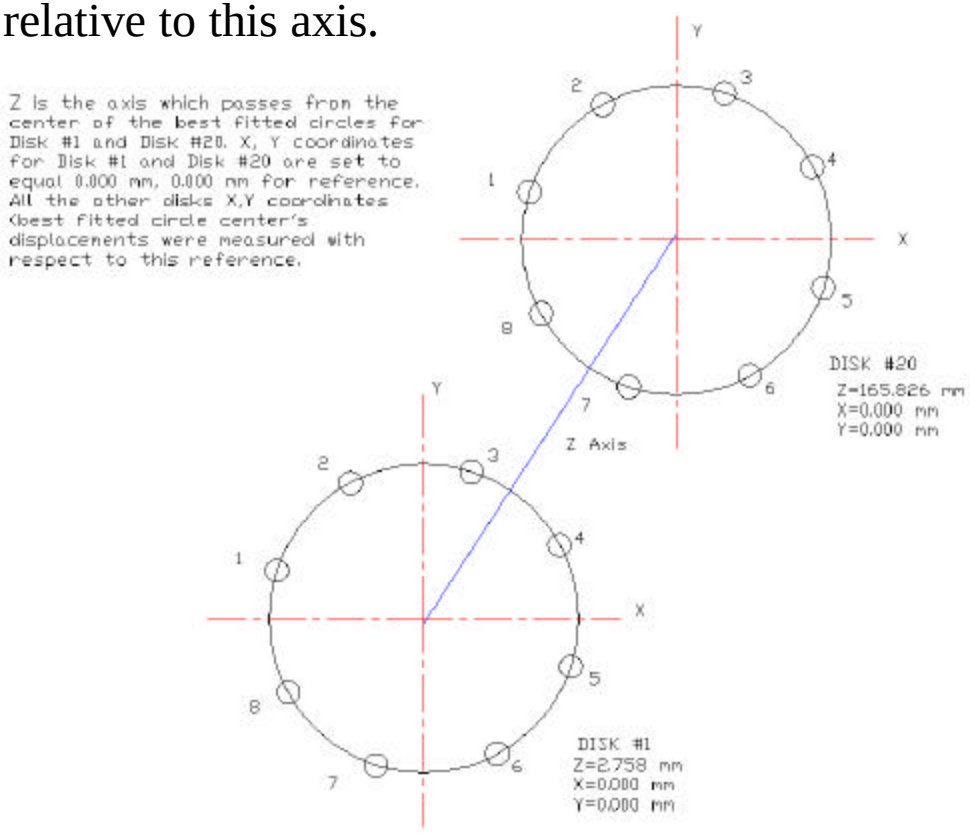
(Presumably FXC needs to be BETTER than FXB, but What Are The Numbers?)

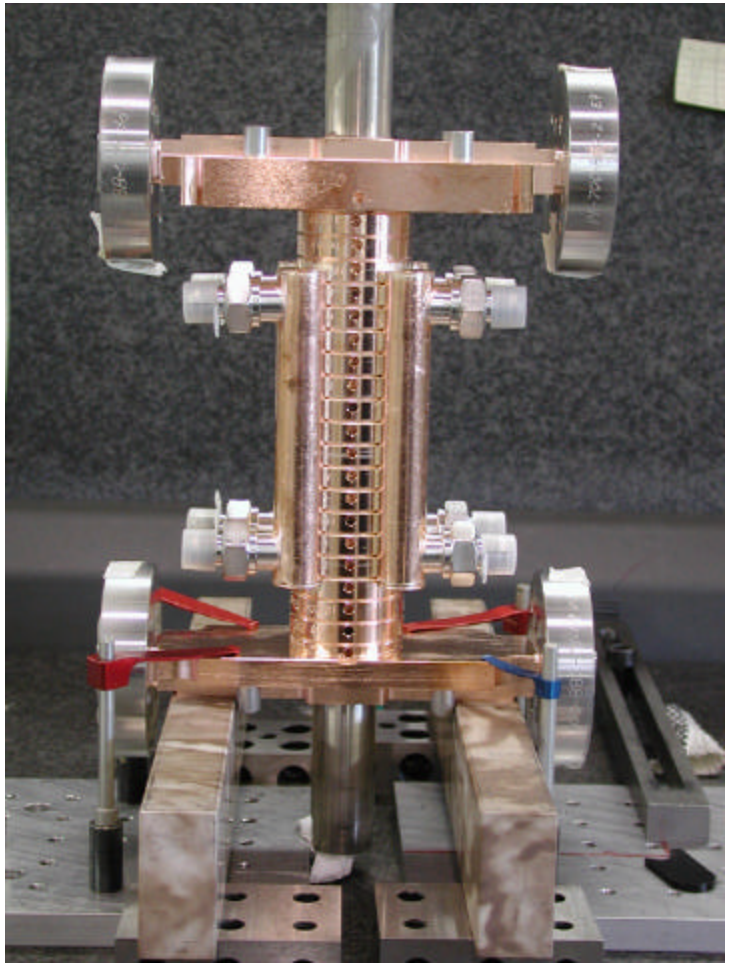
What about vacuum specifications?

Straightness QC on FXA-001 in IB4
(Tug Arkan, Ted Beale, Rob Riley, Harry Carter)

Define the z axis based on disks #1 and #20.

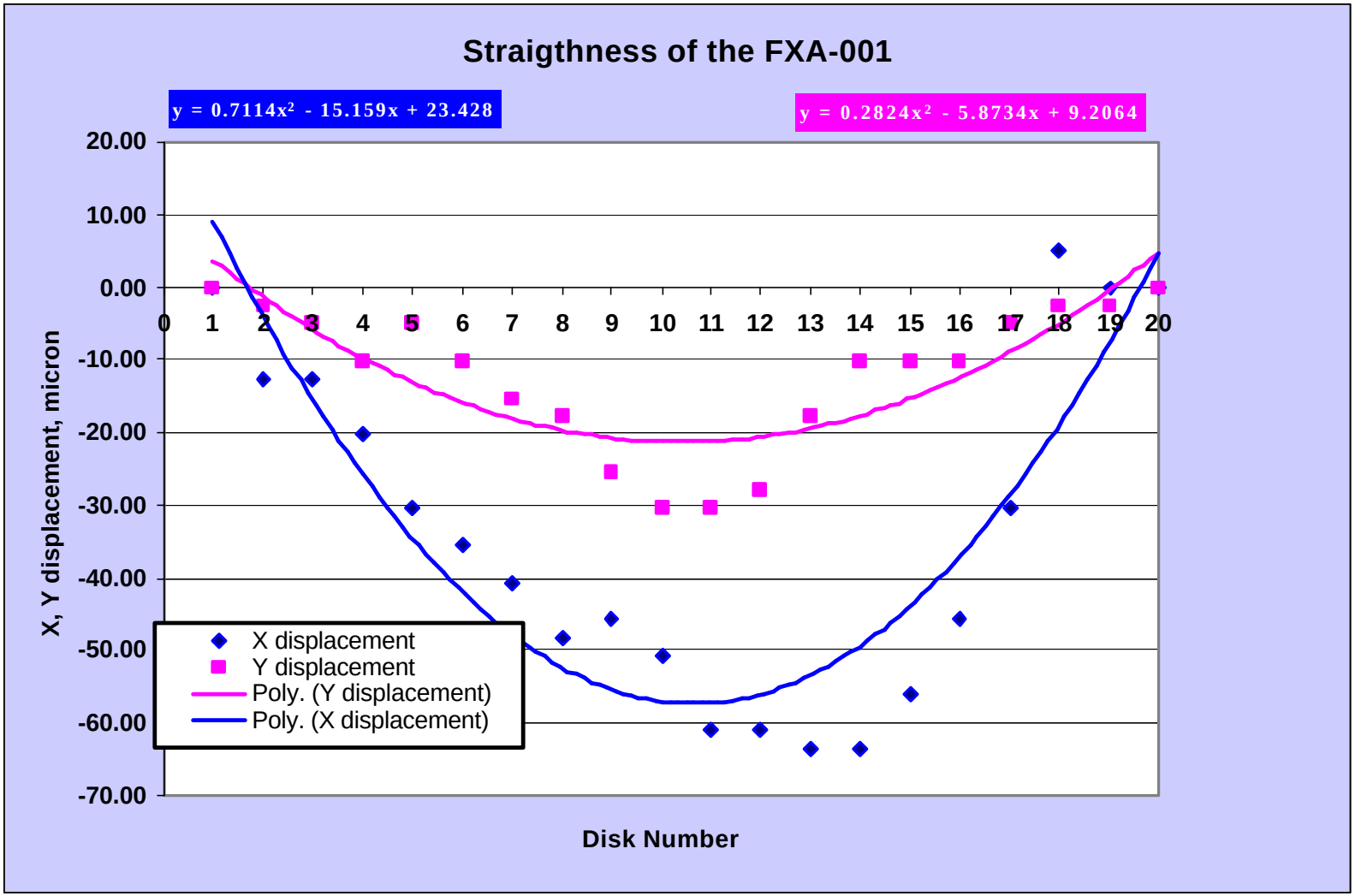
Measure the centers of the other 18 disks relative to this axis.





FXA-001 Setup for Mechanical QC at Fermilab Technical Division, 08/01/01

Straightness QC on FXA-001 in IB4



RF QC on Disks and Complete Structures

Do we need to do RF QC on every disk?

Do we do mechanical QC on disks which fail RF QC?

Is the bead pull method we used for FXA-001 Good Enough?

(Assuming we make it work for 90 cm lengths and 61 mm OD.)

And will we be tuning FXBs? Or is it Pass / Fail?

And will we be tuning FXCs? Or is it Pass / Fail?

RF Measurements on FXA-001

(Gennady Romanov, Ding Sun, Ivan Gonin, Timergali Khabiboulline)

Bead Pull Principle

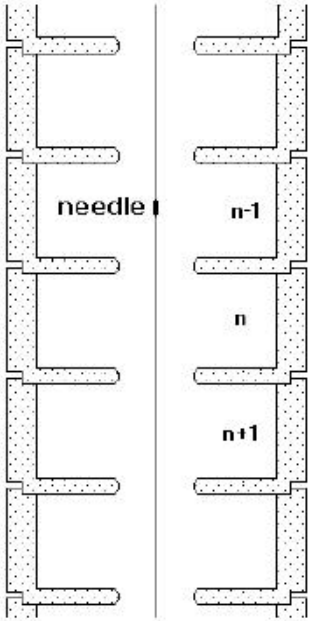


Figure 2.1. Bead-pull measurement.

With the bead-pull method we can measure and calculate amplitudes and phases of the field in the centers of the cells: $A_1e^{j\varphi_1}$, $A_2e^{j\varphi_2}$, $A_3e^{j\varphi_3}$, ... For two neighboring cells with number n-1 and n, let us consider this values as a super-position of forward and backward waves: $a_ne^{j(-2\pi/3(i-n)+\psi_n)}$ and $b_ne^{j(2\pi/3(i-n)+\phi_n)}$, which has passed through n-th disc (between cells n-1 and n).

$$A_{n-1}e^{j\varphi_{n-1}} = a_ne^{j(2\pi/3+\psi_n)} + b_ne^{j(-2\pi/3+\phi_n)} \quad 3.1$$

$$A_ne^{j\varphi_n} = a_ne^{j\psi_n} + b_ne^{j\phi_n}. \quad 3.2$$

The solutions of these two complex equations are:

$$a_ne^{j\psi_n} = (A_{n-1}e^{j(\varphi_{n-1}-\pi/2)} + A_ne^{j(\varphi_n-\pi/6)})/\sqrt{3} \quad 3.3$$

$$b_ne^{j\phi_n} = (A_{n-1}e^{j(\varphi_{n-1}+\pi/2)} + A_ne^{j(\varphi_n+\pi/6)})/\sqrt{3} \quad 3.4$$

From formula (3.4) we can find the amplitude b_n and phase ϕ_n of the backward wave which passed the n-th disc (between cells n-1 and n). For the next (n+1) disc we can use the formula (3.4) to calculate the backward wave:

$$c_ne^{j\eta_n} = (A_ne^{j(\varphi_n+\pi/2)} + A_{n+1}e^{j(\varphi_{n+1}+\pi/6)})/\sqrt{3} \quad 3.5$$

Let us calculate the difference of these two backward waves in the plane of the n-th diaphragm. The phase shift per cell is about $2\pi/3$ and if attenuation can be neglected we can write:

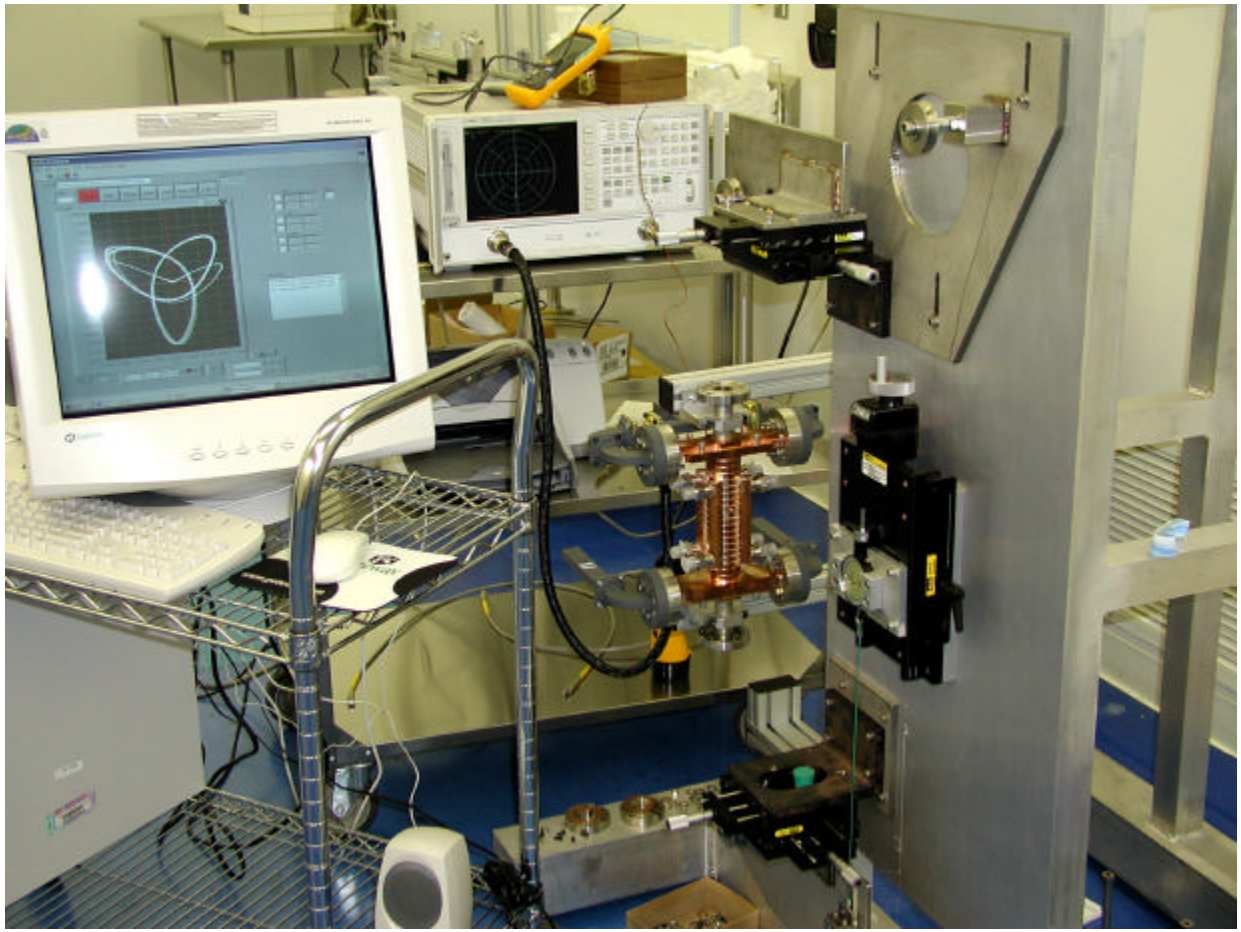
$$S_ne^{j\theta_n} = b_ne^{j\phi_n} - c_ne^{j(\eta_n-2\pi/3)}. \quad 3.6$$

- From PAC95 T. Khabiboulline et al., on DESY LC S-Band setup

- A network analyzer puts an rf wave into the structure composed of cells and couplers. Some of the wave is transmitted, some is reflected. The reflected wave is measured and analyzed.
- A metal "bead" (shown as "needle" in the figure) is pulled along the length of the structure and disturbs the rf wave.
- The analysis yields the amplitude and phase of the reflected wave.

RF Measurements on FXA-001

- Bead pull setup in RF Factory Clean Room A.

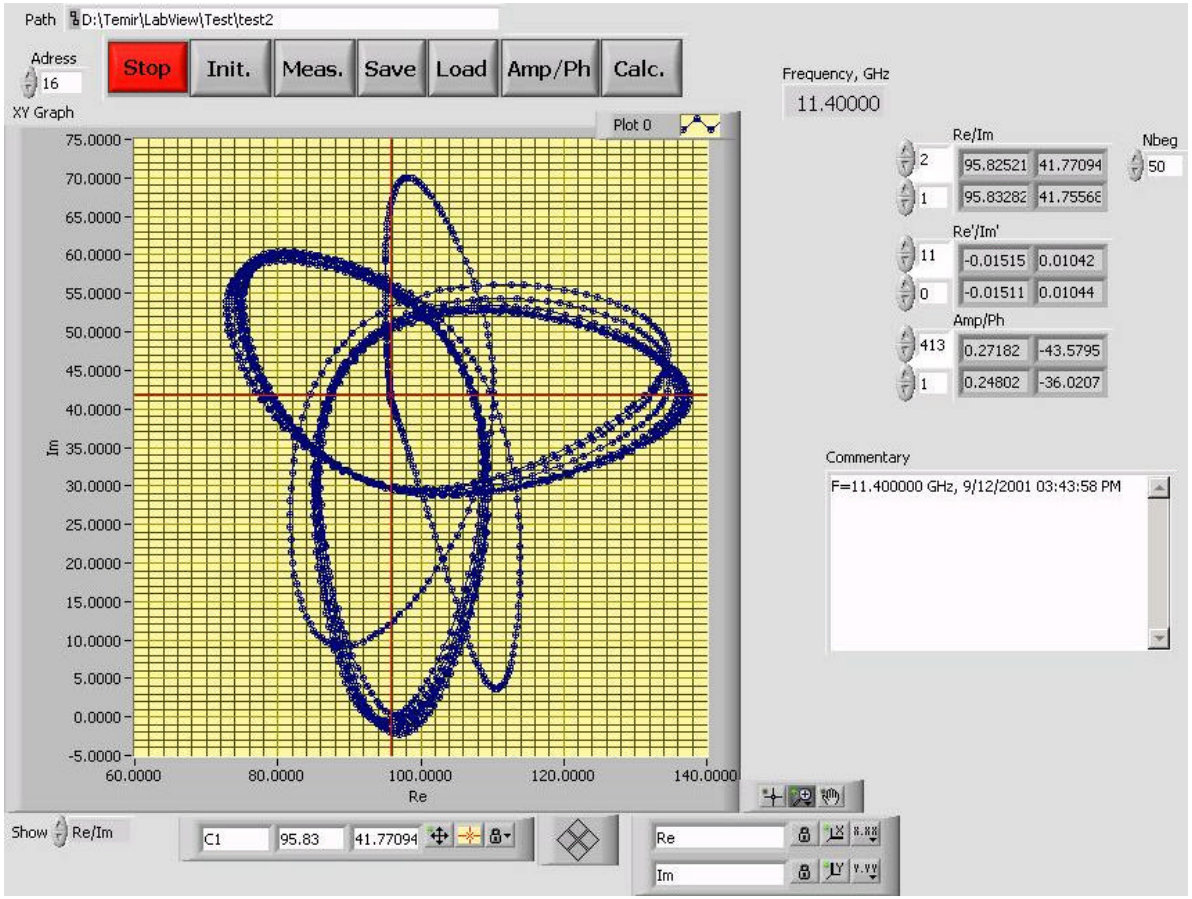


- Note network analyzer (from Beams Division), bead pull support, pulley, data on computer screen, and FXA-001.

RF Measurements on FXA-001

Im vs. Re part of reflected rf wave at 11.400 GHz before tuning.

Note: You want 11.424 GHz; thus these untuned cells are about 24 MHz low.



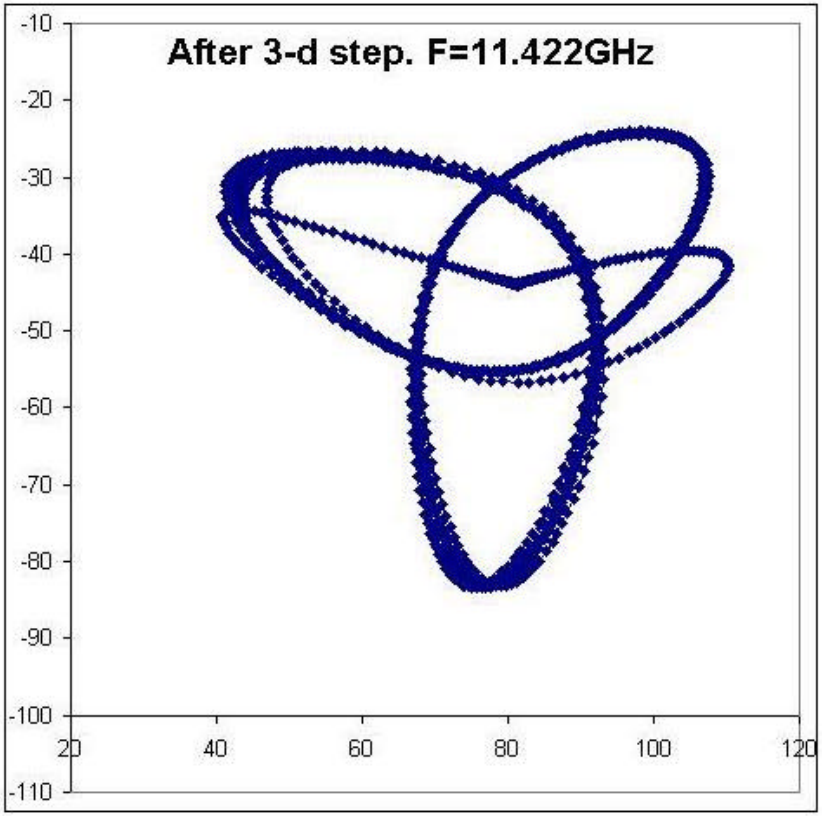
- The bead is pulled through the structure at a constant speed over about 140 seconds.
- Data is taken at constant time intervals and plotted.
- The data taking window is about 10 msec.

RF Measurements on FXA-001

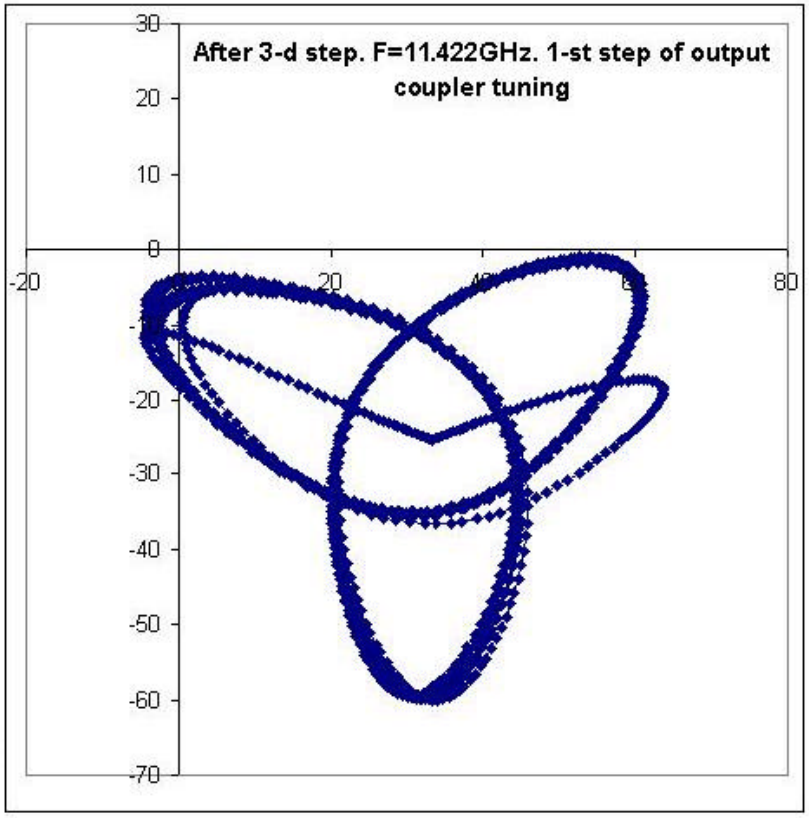
Another Tuning Step: Stay at 11.422 GHz, and tune couplers.

Before

(Same data as "After" on previous slide)

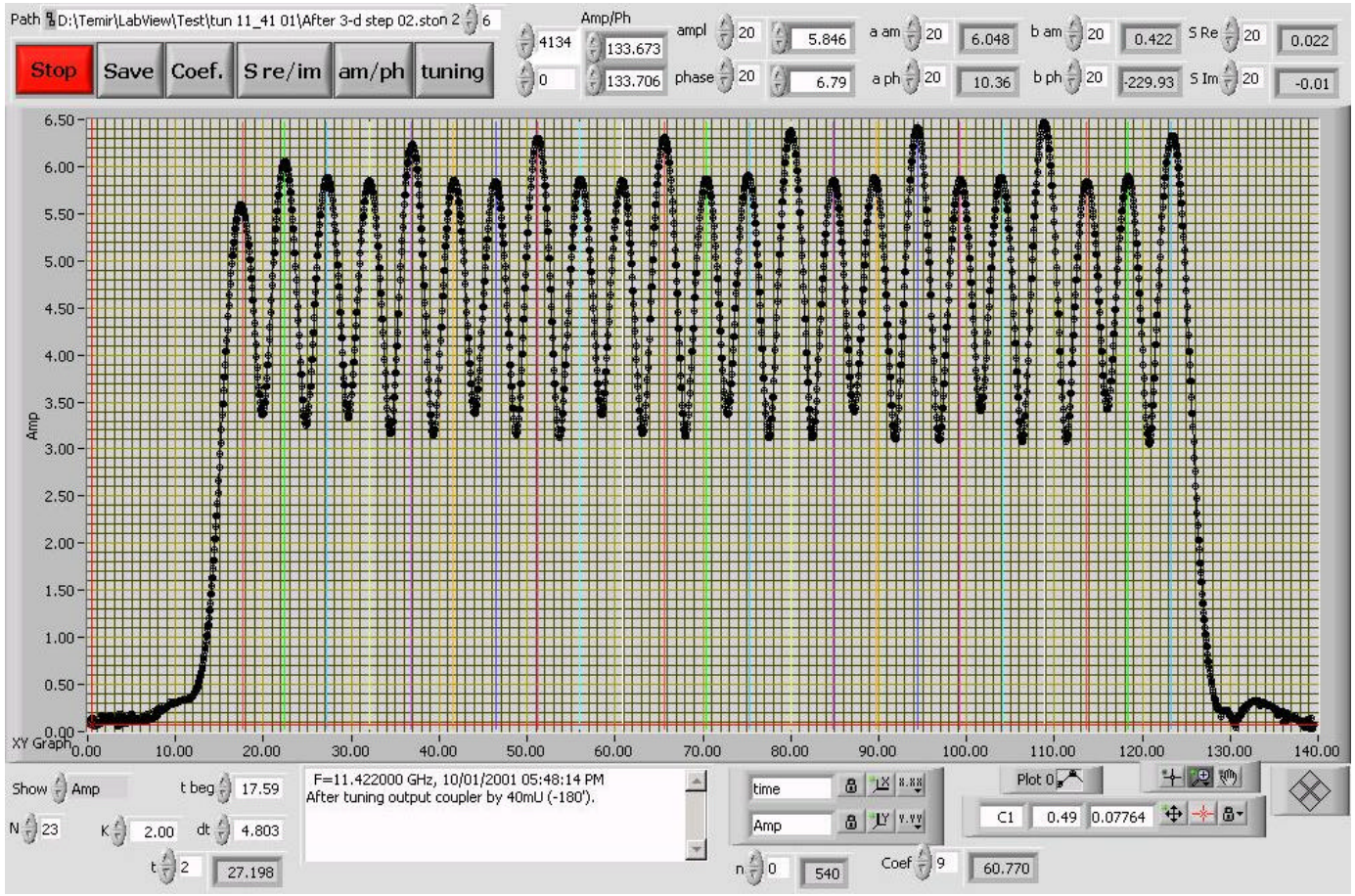


After



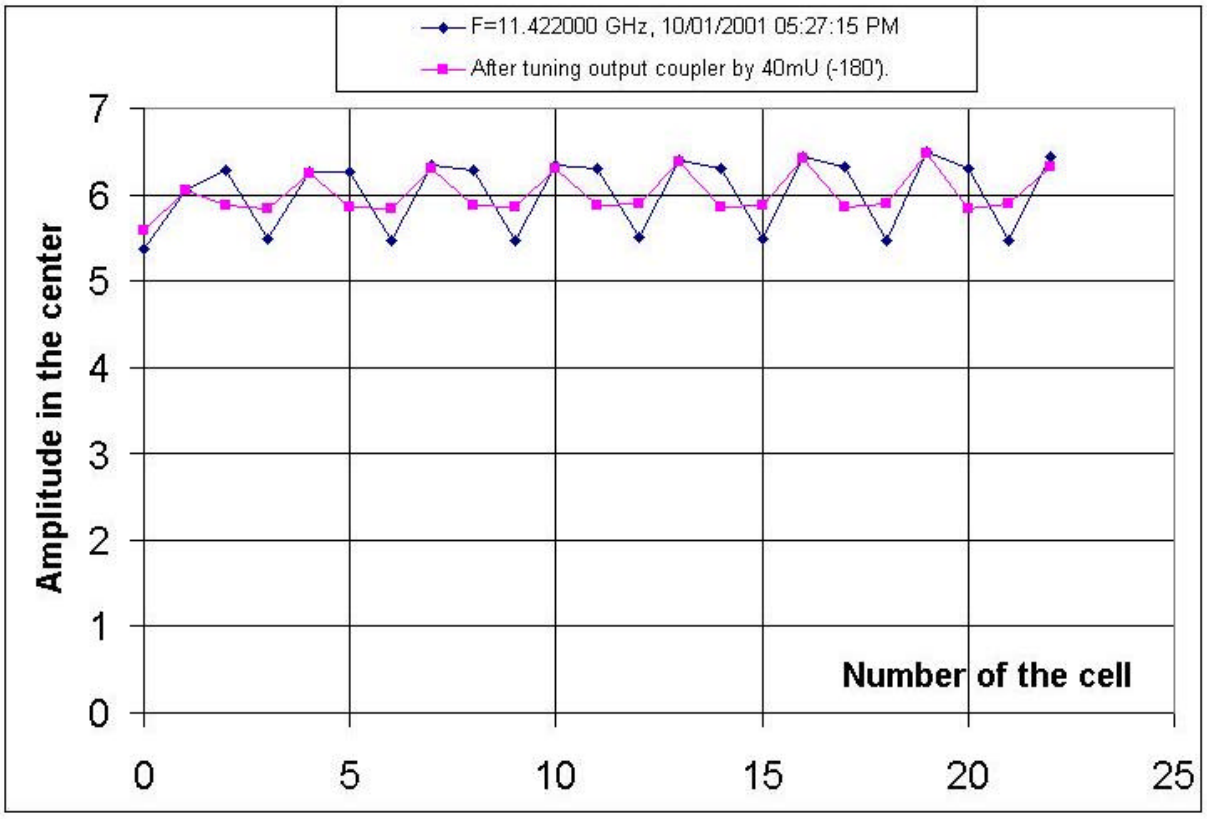
RF Measurements on FXA-001

- Amplitude vs. time after coupler tuning at 11.422 GHz.

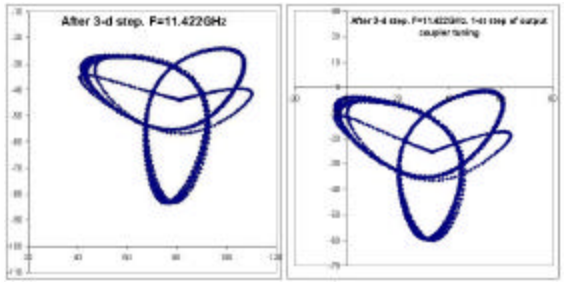


RF Measurements on FXA-001

- Amplitude vs. cell number at 11.422 GHz before and after tuning output coupler.



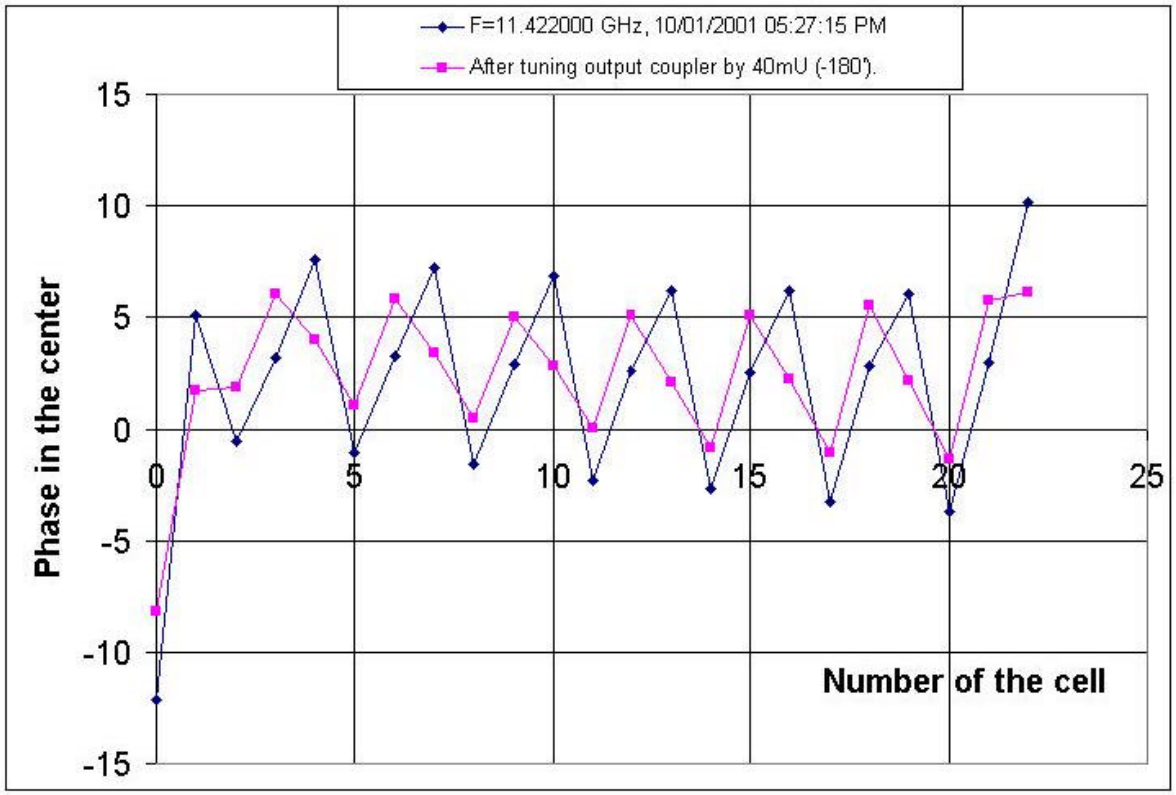
- Same data as:



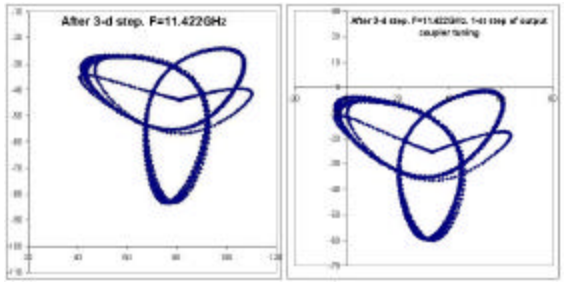
from two slides ago … but the differences are shown more clearly in this plot.

RF Measurements on FXA-001

- Phase vs. cell number at 11.422 GHz before and after tuning output coupler.



- Same data as:



from two slides ago … but the differences are shown more clearly in this plot.

Engineering Teams (as of October 4, 2001). They Are The Way to Develop Specifications and QA. Yes?

For X-Band (NLC)

- **Fermilab RF Factory**
- **Structures (Mechanical)**
- **Structures (Electrical/RF)**
- **Girders**
- **Vacuum System**
- **Cooling Water System**
- **Specifications Development**
- **Quality Assurance Development**
- **8 Pack Integration**

For LC (TESLA and NLC)

- **FNAL Cleaning Facility**
- **SBIRs**
- **Permanent Magnets**
- **Demonstration of Remote Accelerator Operation**
- **Siting LC's near Fermilab**
- **Etc etc**

A Growing List

• Yes, there are names of people associated with each team and they are NOT all from Fermilab in most cases … because the world's best expertise in all these areas does not yet reside at Fermilab.

This RF "Factory" Is Not Quite Radio Shack*

Radio Shack Motto = "You Have Questions. We Have Answers."

Our Motto:
You Have Questions.
We Have More Questions.

Our Founder.

Our First (and Only)

Our Goal

(Yikes!)

FXA-001 September2001
FXA-002 January 2002
FXA-003 April 2002
FXB-001
FXB-002
FXB-OOPs #1
FXB-003 September 2002
FXB-004
FXB-005
FXB-OOPs #2
FXB-006 January 2003
FXC-OOPs #1
FXC-001
FXC-002
FXC-003 May 2003
FXC-004
FXC-005
FXC-OOPs #2
FXC-006 September 2003

*Borrowed / Paraphrased from Radio Shack Commercials

QC Needs for FXB and FXC Structures for 8 Pack Test

- What is The Goal? What is the Plan?
- (An aside on the A, B, C's of Names)
- Details: Engineering Teams and Documentation
- QC Perceived Needs and Questions

The End.