X-band RF Structure Fabrication at Technical Division, Fermilab

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ISG9

December 10-13, 2002

Outline

- RF Structure Factory
- Structure Fabrication
  - FXA-003
  - Dummy 0.6-meter Structures
  - FXB-002
  - Lessons learned
- FCX Disk Manufacturability R&D

RF Structure Factory

- FNAL Technical Division Structure Group's goals for the RF structure R&D factory:
  - RF design (TD RF Engineering Group)
  - RF disk fabrication
  - RF disk quality assurance
  - RF structure fabrication
  - RF structure quality assurance
  - Infrastructure setup for all above
- Major infrastructure of the factory are:
  - Two clean rooms, RF QC area and a work area
  - Vacuum Furnaces inside soft sided clean room
  - Clean room Leak Detector, Clean room Pumping Station, RGA, Anaerobic Chambers etc.

Clean Rooms

Clean Room A (Class 3000)

Clean Room B (Class 1000)

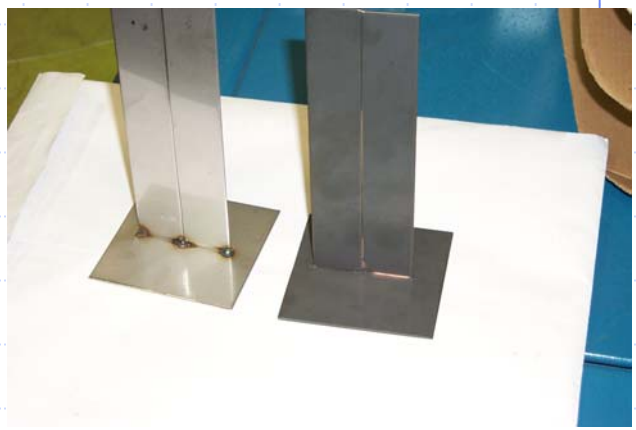
Small Vacuum Furnace

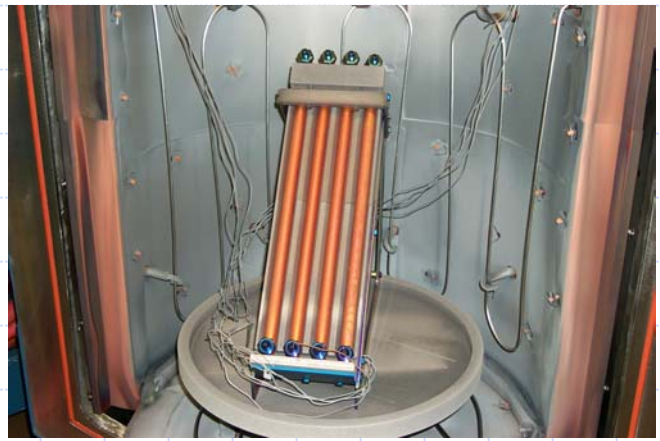
Small Vacuum Furnace was installed on September 01. Presently in use for RF Structure sub-assembly fabrication and brazing/bonding studies

Large Vacuum Furnace

1. The furnace was delivered to FNAL on June 2002, 3 months late
2. The installation and commissioning were completed July 2002
3. The furnace started to leak after 10 heat cycles Major Problems:
   - Bad power feed-through design
   - Bad power feed-through insulation scheme
   - Bad thermocouple feed-through design
   - Undersized Heaters
4. The furnace leaks are routinely fixed before each run, after each heat cycle, a new leak opens at power feed-throughs due to the stress caused by the thermal expansion/contraction of the heating elements

Large Vacuum Furnace-II





Furnace Repair Status

- Hot zone shield pack is taken out and cleaned
- All the ceramic insulators are replaced
- All the molybdenum supports are cleaned
- The damaged heaters are replaced with new ones
- Old thermocouple feedthroughs are replaced with CONAX type connectors
- A new reflective shield is installed in order to keep the cryo pump cool

- Small Furnace company president came as a consultant to review the repair process plans and also consult the use of the AVS furnace. He will make recommendations

- AVS machined new power feedthroughs with correct dimensions
- AVS added new insulations (Fiberfrax, Alumina) to the feedthoughs. Only Fiberfrax is used.

- Bake out cycle: 5C/min ramp, 300C, 60 minutes, vacuum
- Bake out cycle: 5C/min ramp, 500C, 360 minutes, 500 micron Argon
- The upper zone back power feedthrough is installed almost touching to the upper zone over-temperature thermocouple. It shorted the thermocouple, damaged the shield on the thermocouple and caused a major leak. The hot zone got oxidized.
- Clean up cycles & Test runs

RF Disk & Coupler Fabrication

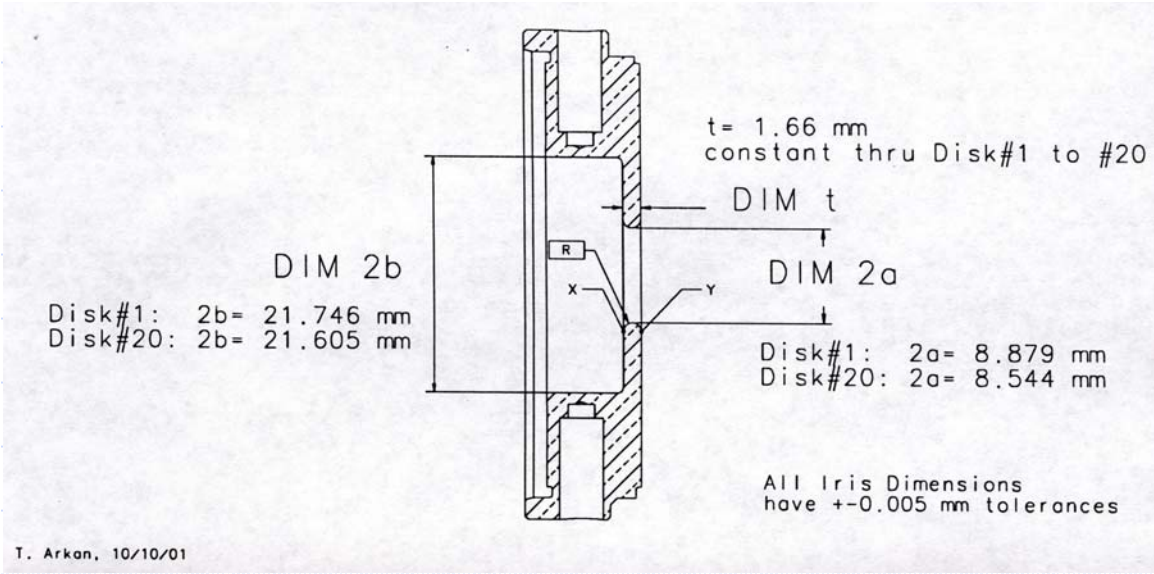
- Outside High Precision and Diamond Turning Machine Shops were used
- There is an existing technology and industry, maximize the competition and minimize the cost
- Identify more local vendors. Always keep the industrialization long term goals in mind
- For FXA's:
  - RF Disks from MEDCO, High Precision Machine Shop
  - RF Couplers from CMM, Diamond Turning Shop
- For FXB's:
  - RF Disks from MEDCO & LaVezzi, High Precision Machine Shops
  - RF Couplers from CMM, Diamond Turning Shop for Fermi fat-lipped couplers
  - RF Couplers from High Precision Machine Shops (Medco) for Fermi mode launch couplers (Nantista design)

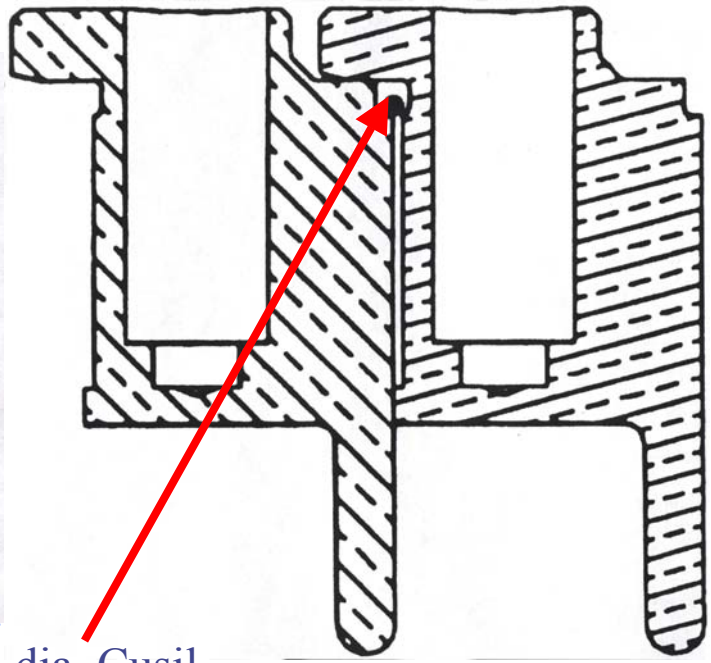
FXA-003 Fabrication - Description

- FXA-003 is the last 20-cm structure produced by Fermilab
- FXA-003 is a 45-mm OD 20-disk high gradient test structure
- Design is identical to SLAC T20VG5 structure (except for brazing grooves in disks)
- This is an all-brazed structure (no diffusion bonding)
- Disks are precision machined (no diamond turning)
- Couplers are precision machined with some diamond-turned RF surfaces (in the iris area)
- All brazing operations were conducted in Fermilab Small & Large Vacuum Furnaces

FXA-003 RF Disk Details

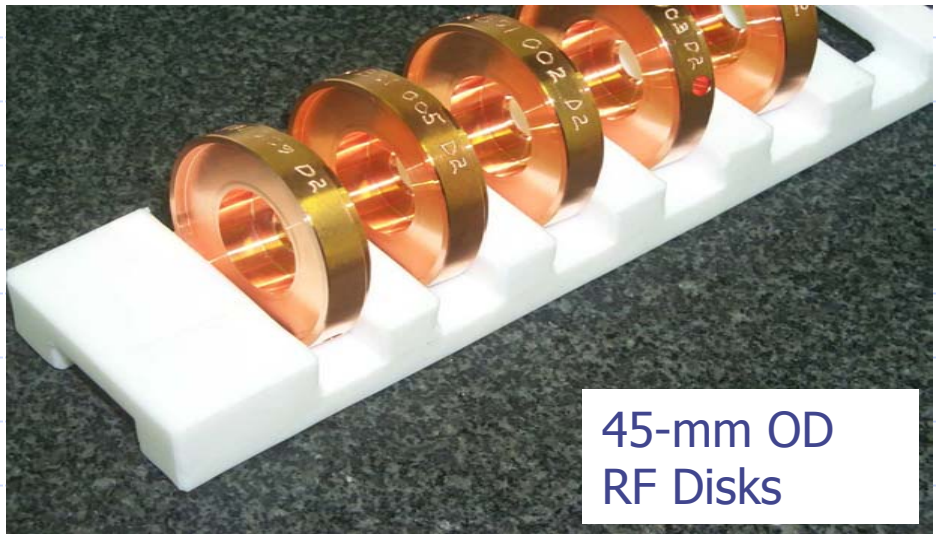
- 2a, 2b, thickness (t) and profile of iris.

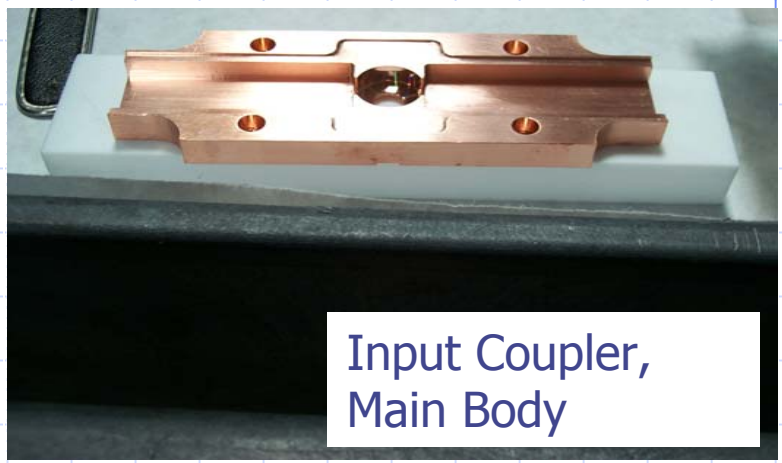


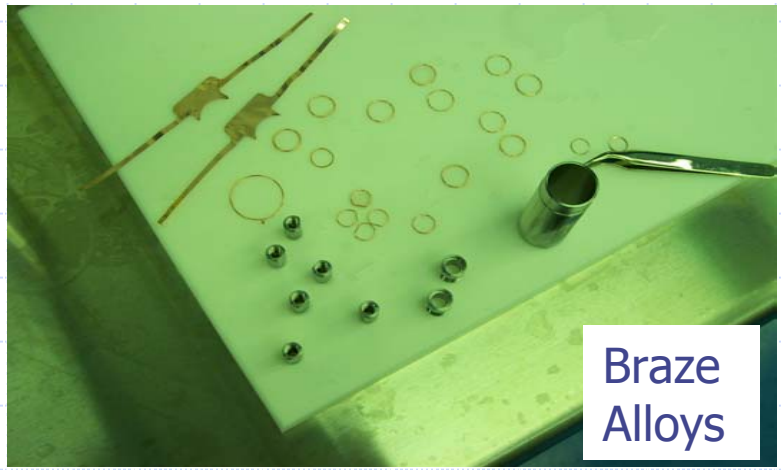


0.75 mm dia. Cusil wire

FXA-003 Parts







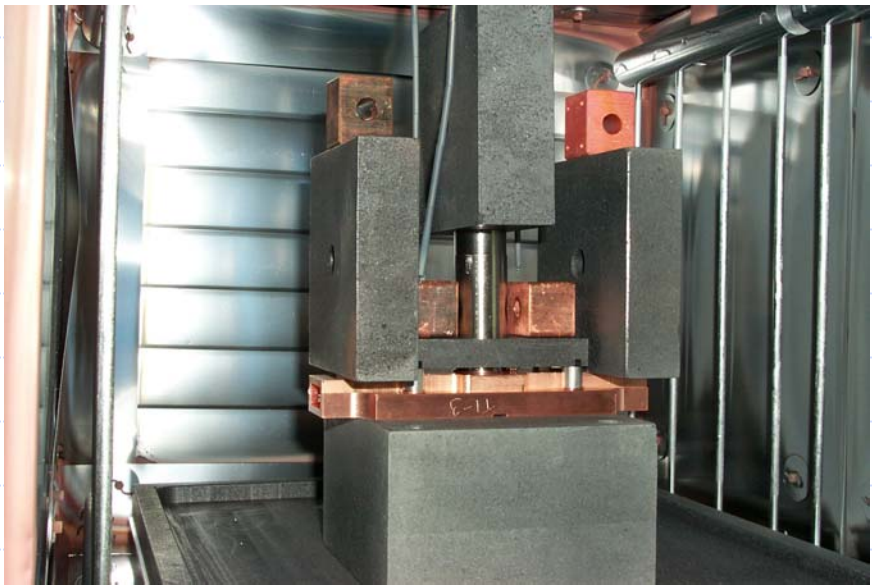
Each RF Disk is scribed with an unique identification number to distinguish, the design, vendor, disk and serial number

FXA-003 Brazing – Water Tubes

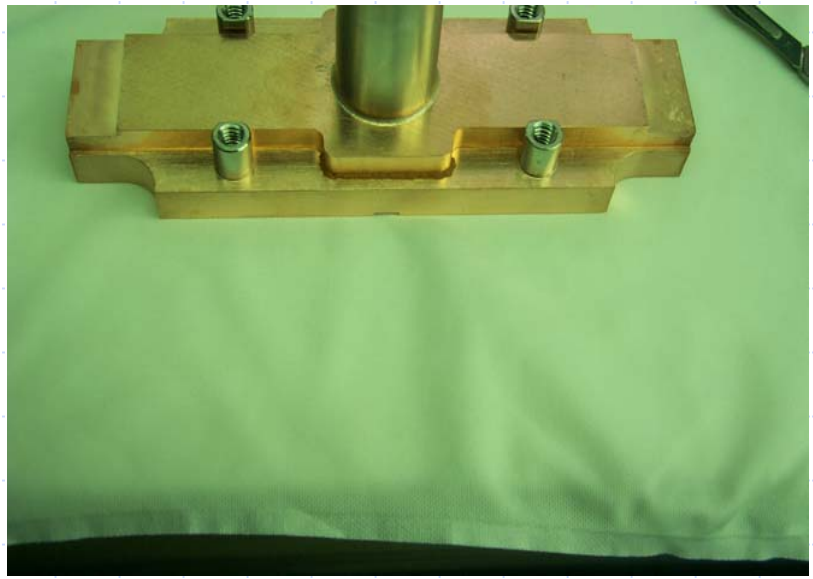
Four Water Cooling Tubes were brazed in the FNAL small vacuum furnace

- Brazing Alloy: 35% Gold + 65% Copper
- Braze Temp./Time: 1030 ^{o}C / 5 min.

FXA-003 Brazing – Couplers



Output Coupler Sub-Assembly in the brazing fixture on the hearth of the FNAL small vacuum furnace

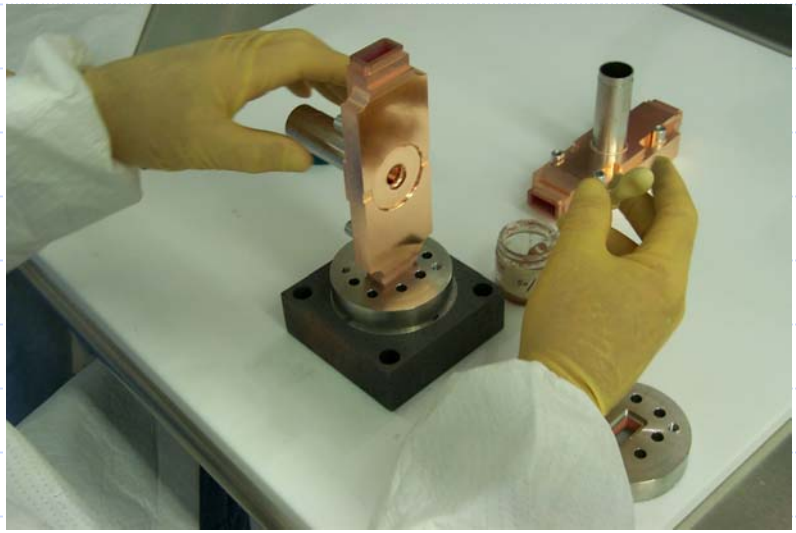


Brazed and Leak Checked completed Input Coupler Sub-Assembly

- Brazing Alloy: 35% Gold + 65% Copper
- Braze Temp: 1030 ^{o}C / 5 min.

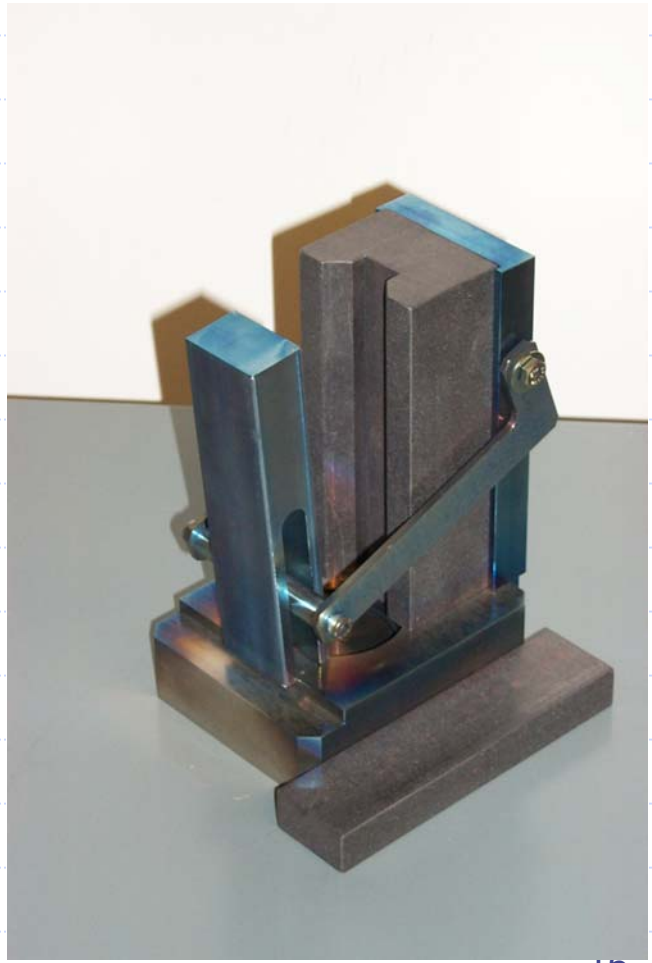
FXA-003 Brazing – RF Flanges

- After the machining of the ends of the brazed coupler sub-assembly, RF Flanges are brazed:
  - FNAL Small Vacuum Furnace
  - Brazing Alloy: 50%Cu +50%Au
  - Braze Temp./Time: 970 ^{o}C / 5 min.

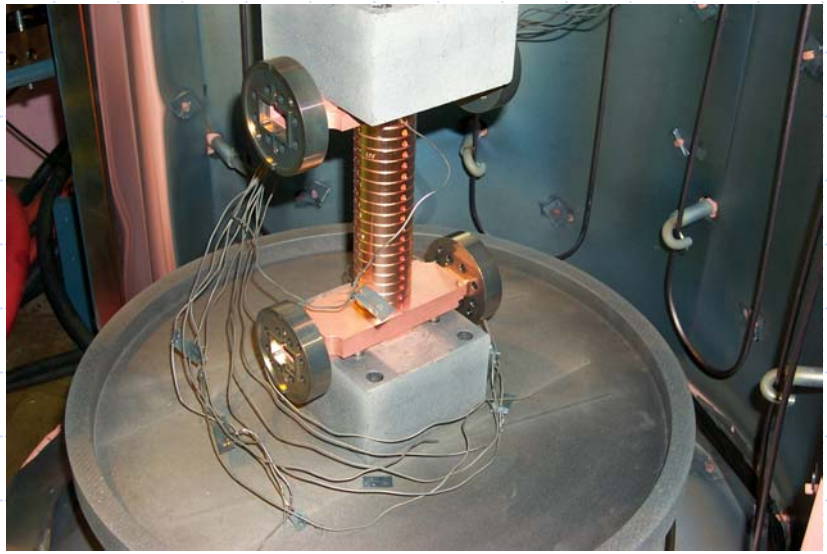


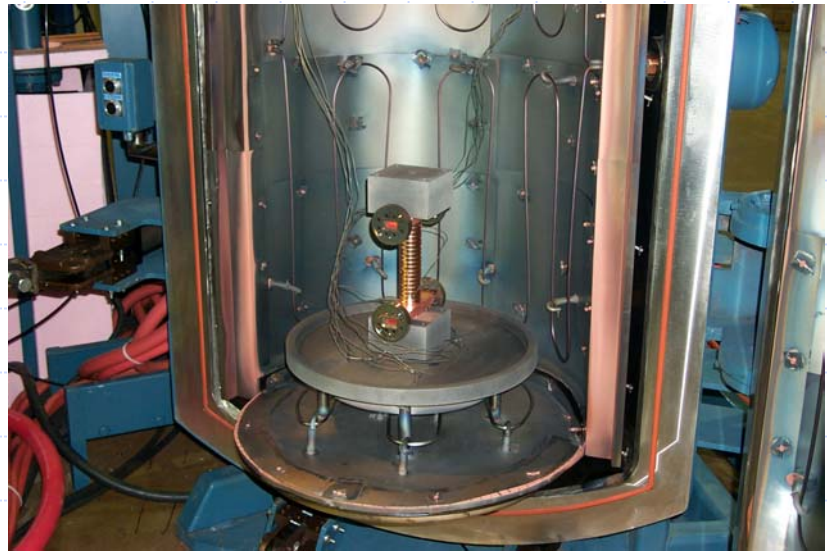
FXA-003 Brazing – Disk Stack

- FNAL Small Vacuum Furnace
- Brazing Alloy: Cusil (28%Cu + 72% Ag)
- Braze Temp./Time: 790 ^{o}C / 10 min.



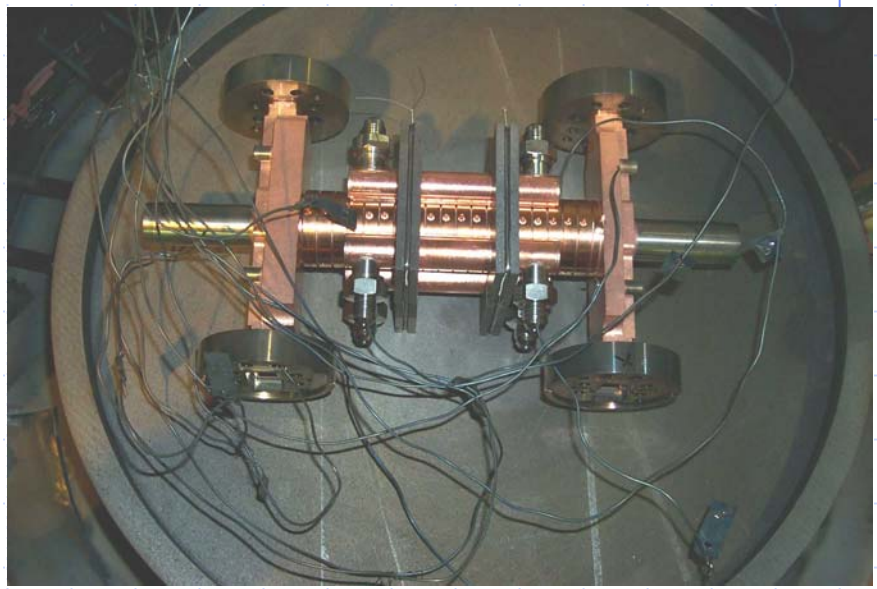
FXA-003 Brazing – Disk Stack to Couplers





- **Disk Stack to Coupler Brazing**
  - FNAL Large Vacuum Furnace
  - Brazing Alloy: Cusil (28%Cu + 72% Ag)
  - Braze Temp./Time: 790 ^{o}C / 10 min.

FXA-003 Brazing – Final



- **Water Cooling Tubes-to-Structure Brazing**
  - FNAL Large Vacuum Furnace
  - Brazing Alloy: Incusil (61.5% Ag + 23.5% Cu + 15% In)
  - Braze Temp./Time: 725 ^{o}C / 15 min.

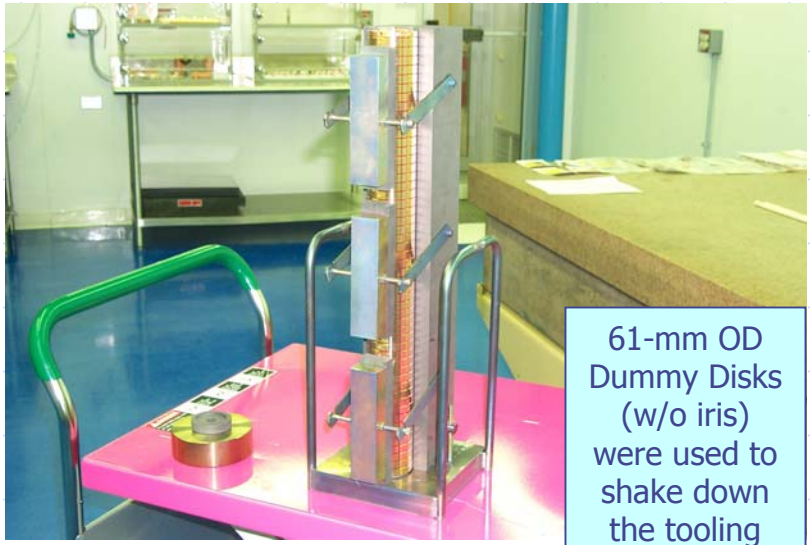
FXB-002 Fabrication

- From FXA's to FXB's:
  - Disk OD is increased to 61-mm, the brazing groove design is not changed, the brazing groove is at 45-mm OD
  - New Couplers with larger horn radius (fat-lipped coupler)
  - Both Disks (60 seconds) and Couplers (5 seconds) are etched with SLAC's etching procedure
  - New Tooling for Assembly
  - New Tooling for Leak Check
  - More Care for cleanliness during assembly
  - Clean Room working and proper attire procedures are revised
  - Soft sided Clean Room is placed around the vacuum furnaces

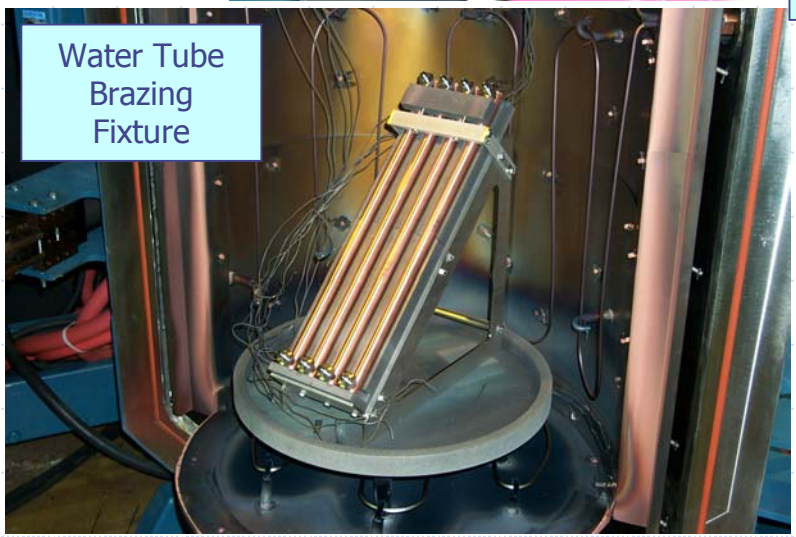
FXB-002 Fabrication - Description

- FXB-002 is the first 0.6-meter long structure produced by Fermilab
- FXB-002 is a 61-mm OD 52-disk high gradient test structure
- Design is identical to SLAC H60VG3 structure (except for brazing grooves in disks, larger OD for the disks and Fermi designed fat-lipped couplers).
- This is an all-brazed structure (no diffusion bonding)
- Disks are precision machined (no diamond turning)
- Couplers are precision machined with some diamond-turned RF surfaces (in the iris area)
- RF Parts were cleaned & etched with SLAC's procedure
- Sub-Assembly (Couplers) brazing of the structure were conducted in FNAL small vacuum furnace
- Water Tubes. RF Disk Stack to Couplers and Water to tubes to RF Disk Stack Brazing Operations were done in a vacuum furnace at ATP, a local heat treating shop at Bensenville, IL
- Structure is not intentionally exposed to Hydrogen during brazing

Dummy Structure Fabrication



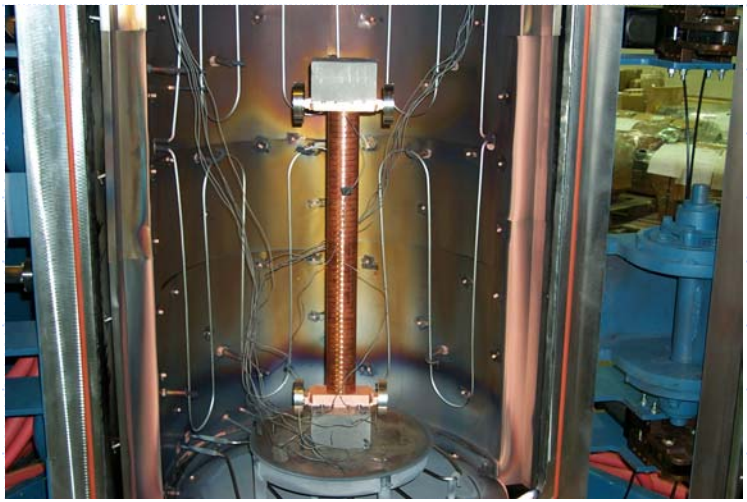
61-mm OD Dummy Disks (w/o iris) were used to shake down the tooling



Water Tube Brazing Fixture

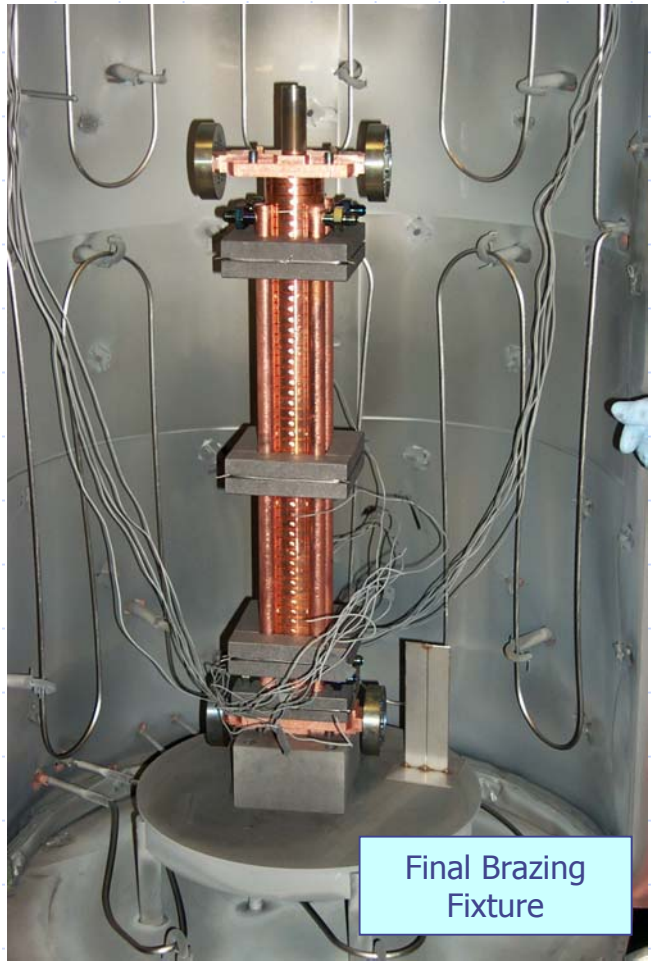
V-Block Disk Stacking - Brazing Fixture

Dummy Structure Fabrication



Except the coupler brazing, all the brazing processes of FXB type structures have to be done in the large vacuum furnace

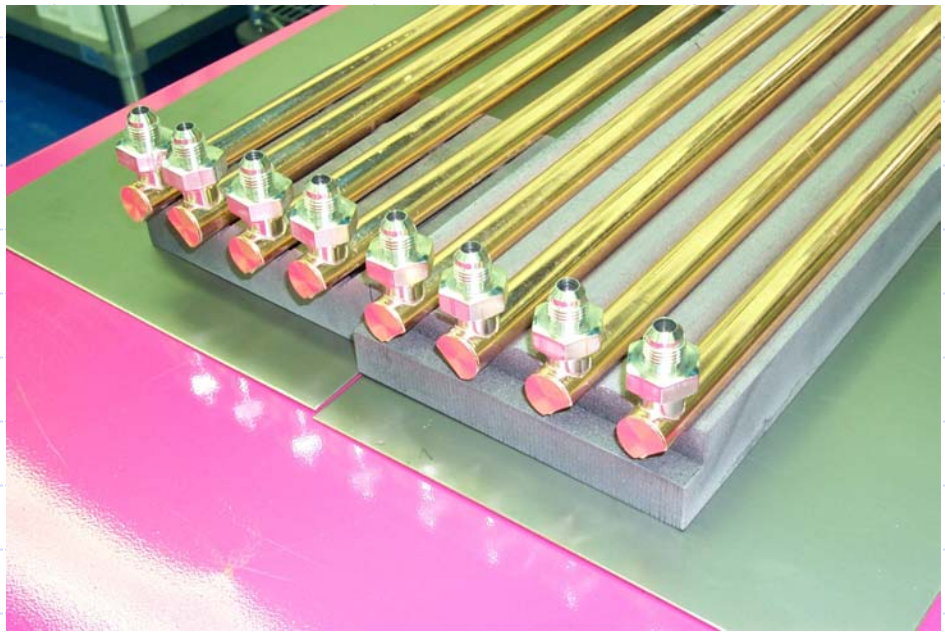
New Tooling, New Furnace, New Structure --- R&D



Large Vacuum Furnace at ATP

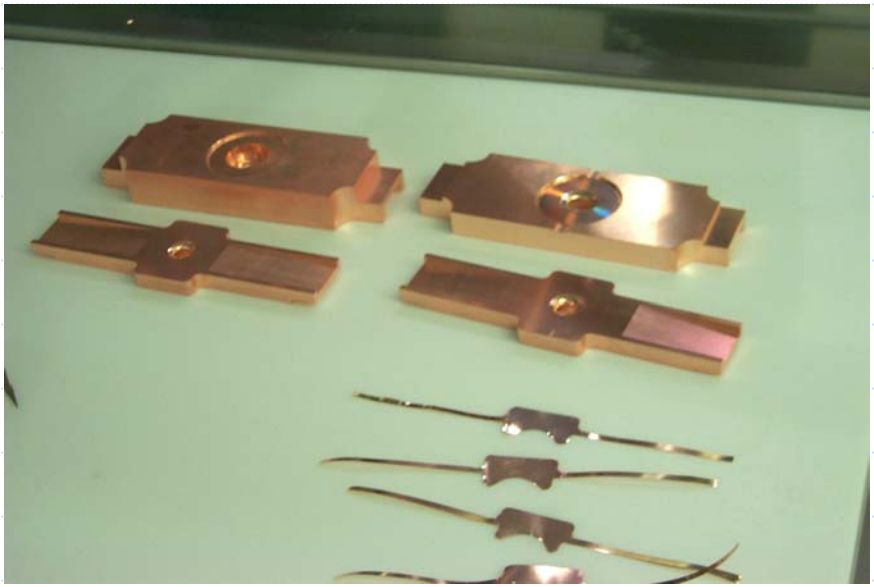
- Molybdenum Heaters
- Graphite Shields
- Dry Roughing Pump
- Diffusion Pump
- Used mostly for SS parts baking & annealing
- Some Prior Hydrogen use
- Bake out cycle before Structure Brazing

FXB-002 Brazing – Water Tubes



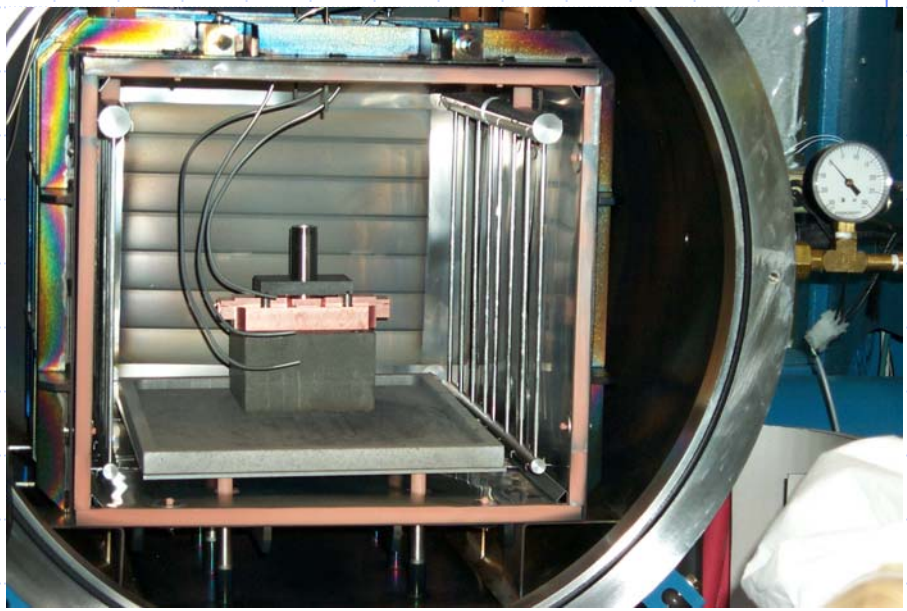
- Water Cooling Tubes were brazed in the ATP large vacuum furnace
- Flat Carbon trays with accommodating grooves were used
- Brazing Alloy: 35% Gold + 65% Copper
- Braze Temp./Time: 1030 ^{o}C / 10 min.

FXB-002 Assembly – Couplers



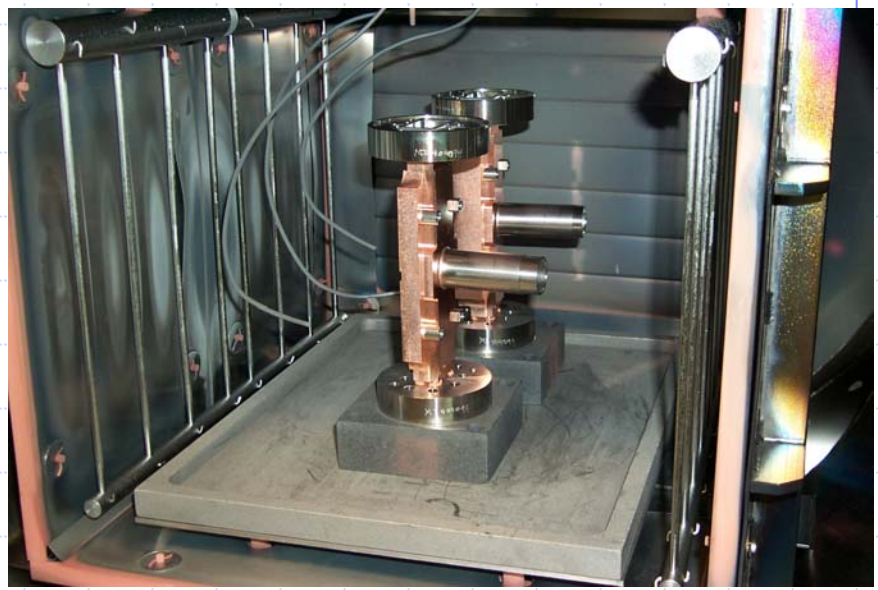
- Coupler parts were etched and transported to the Clean Room in the Alcohol Bath
- Coupler parts were dried with filtered nitrogen and assembled under a Class 10 Hood

FXB-002 Brazing – Couplers



- FNAL Small Vacuum Furnace
- Brazing Alloy: 35% Gold + 65% Copper
- Braze Temp: 1030 °C / 10 min.

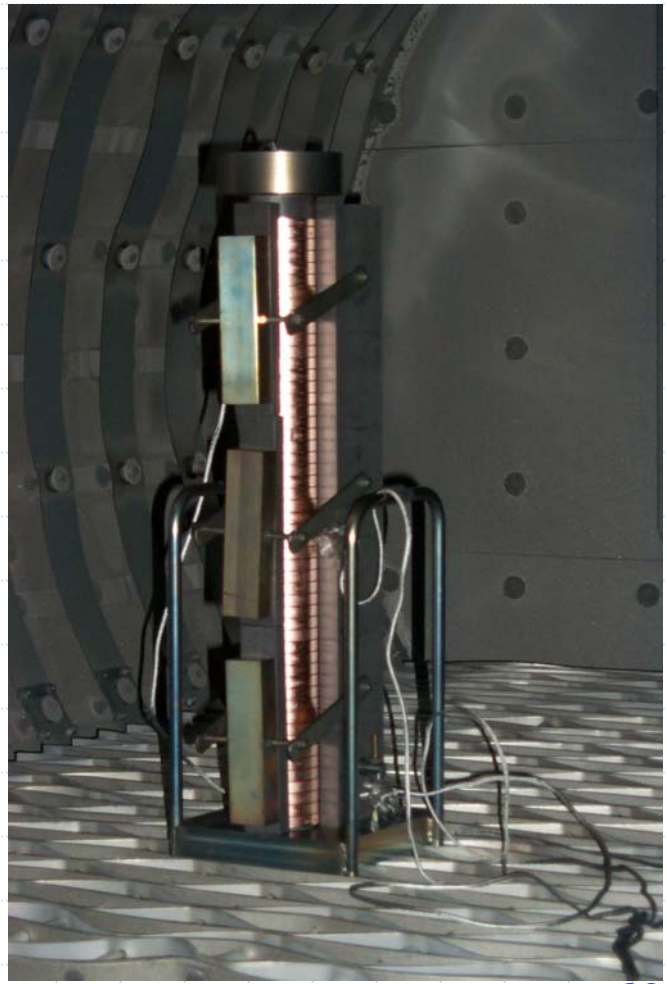
FXB-002 Brazing – RF Flanges



- FNAL Small Vacuum Furnace
- Brazing Alloy: 50%Cu +50%Au
- Braze Temp./Time: 970 ^{o}C / 10 min.

FXB-002 Brazing – Disk Stack

- ATP Large Vacuum Furnace
- Brazing Alloy: Cusil (28%Cu + 72% Ag)
- Braze Temp./Time: 800 ^{o}C / 30 min.
- Longer Soak times in order to get temperature stabilization through large mass of the carbon V-block tooling and larger 61-mm OD RF disks

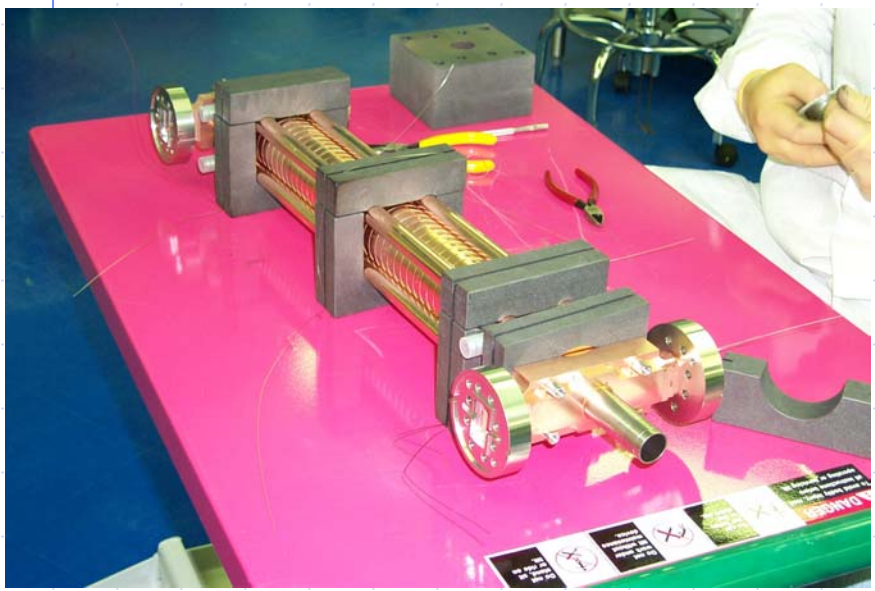


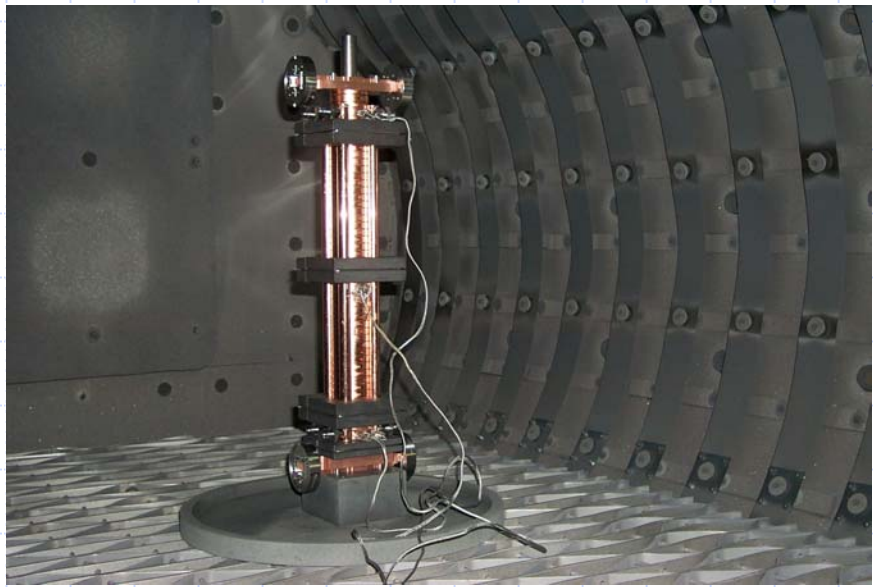
FXB-002 Brazing – Disk Stack to Couplers

- 0.030 inch thick Cusil wire was wrapped around each disk joint in order to ensure a helium leak tight structure during the brazing of the couplers to the already brazed disk stack
- Longer Soak times in order to get temperature stabilization

- ATP Large Vacuum Furnace
- Brazing Alloy: Cusil (28%Cu + 72% Ag)
- Braze Temp./Time: 800 ^{o}C / 30 min.

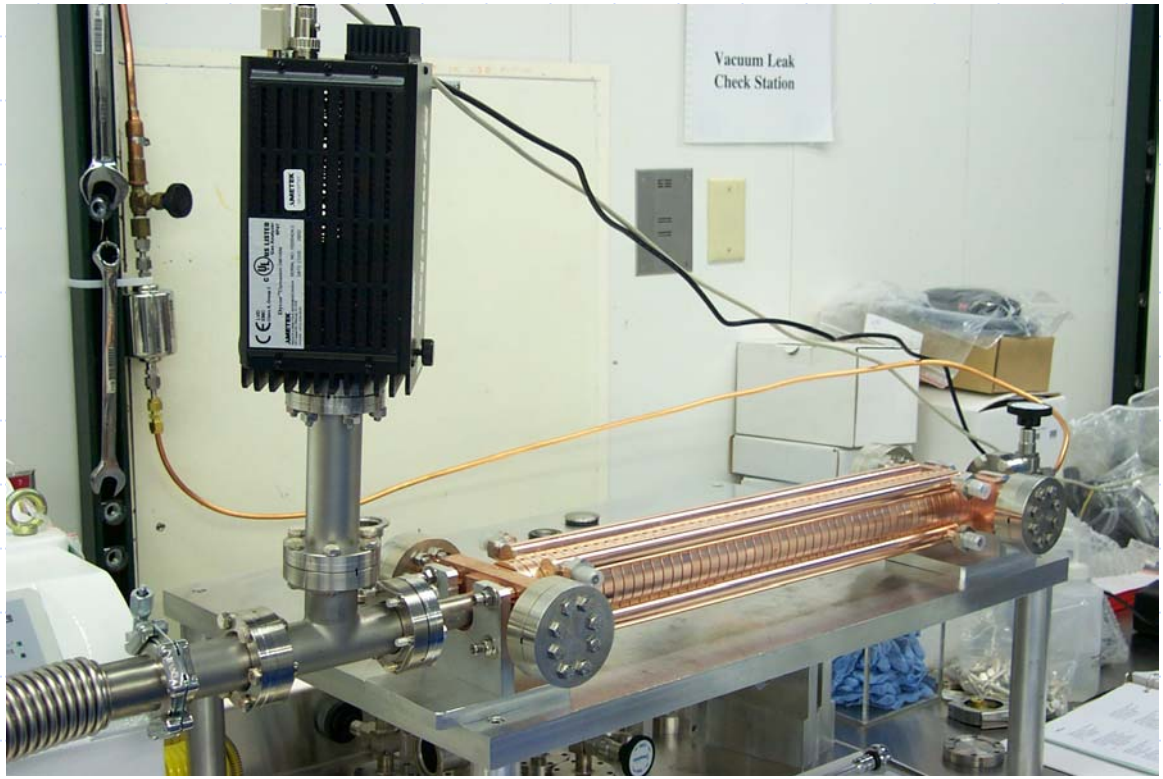
FXB-002 Brazing – Final



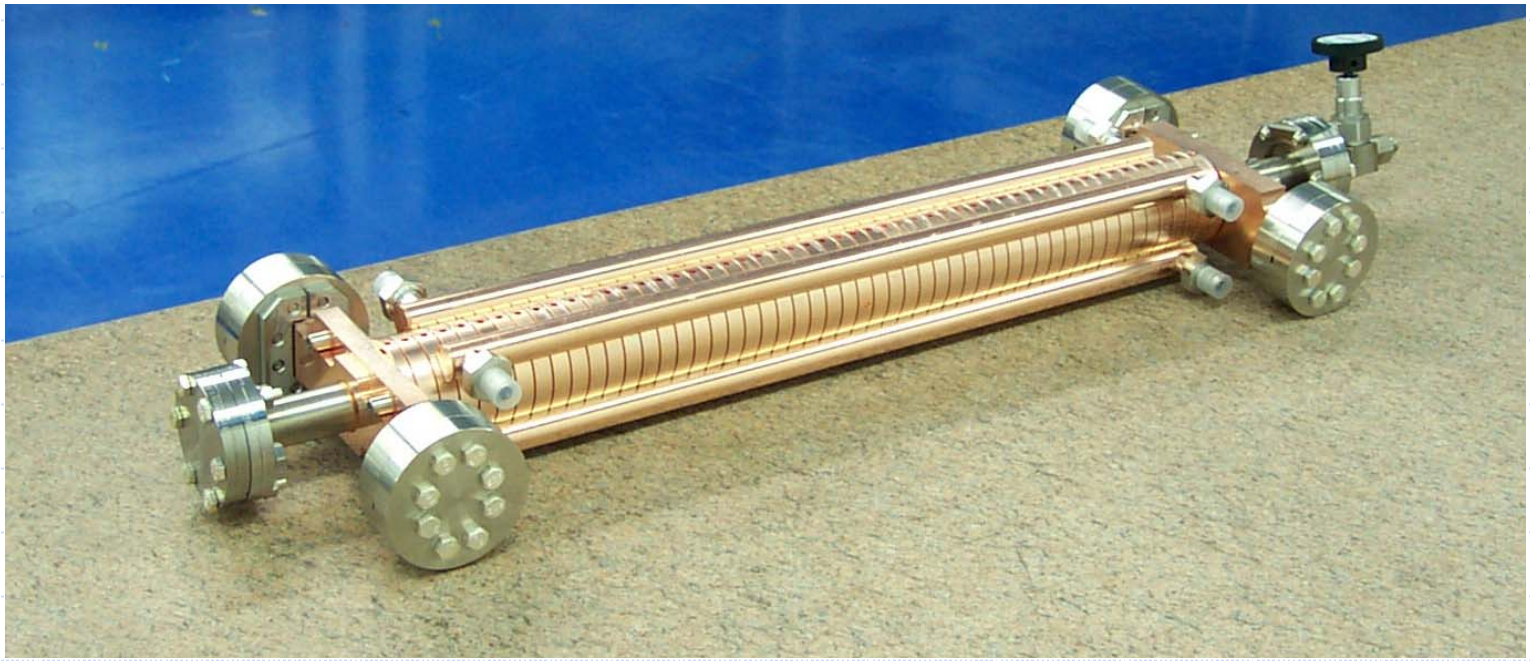


- ATP Large Vacuum Furnace
- Brazing Alloy: Incusil (61.5% Ag + 23.5% Cu + 15% In)
- Braze Temp./Time: 725 ^{o}C / 30 min.

RGA in Room Temperature

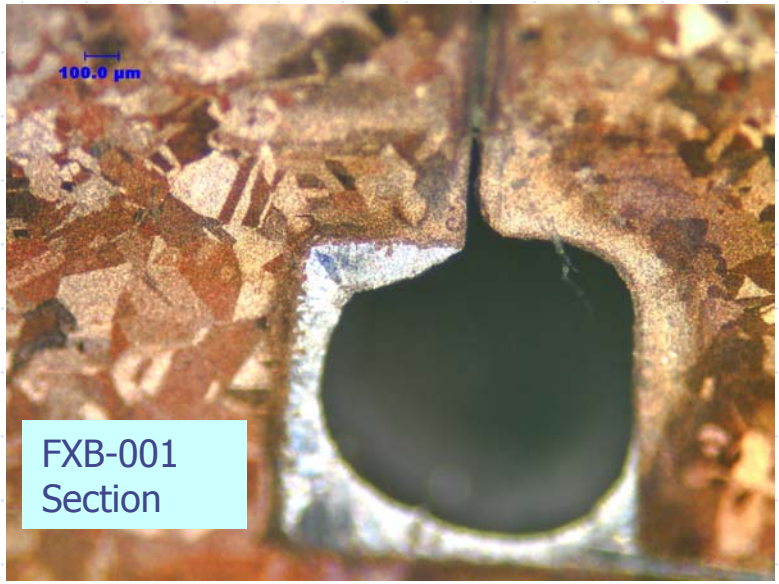


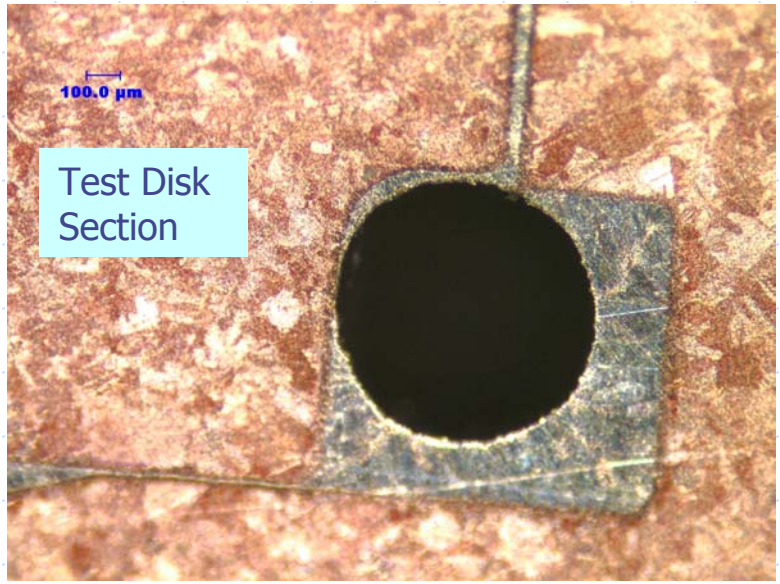
Completed FXB-002



FXB-002 & FNAL Folks at NLCTA

FXB-001





The braze material reached its melting point but did not have enough soak time to flow in the designed braze groove for FXB-001 disk stack

Higher temperature and longer soak time used for FXB-002 disk stack brazing

Tug Arkan

Lessons Learned from FXB-002

- RF Parts cannot be left in the alcohol bath after etching more than 48 hours, they become oxidized
- The integrity of the brazing operation should not be only evaluated with helium vacuum leak check, mechanical integrity does not depend on the leak tight criteria
- CUSIL brazing wire thickness for the RF Disks brazing of further structures will be increased from 0.030 inch to 0.035 inch in order to ensure a more guaranteed fill of the brazing groove between the disks
- During a brazing heat cycle, the temperature distribution throughout the tooling and the parts have to be carefully monitored and adequate soak times have to be allowed in order the braze alloy melts and flow
- The disk stack straightness changes with handling. The stack can be straightened with couple of taps on the body while laying on a granite table
- During the leak check of the structure, RF Flanges have to be sealed. While tightening the bolts on the flanges, it is likely that the flange will be distorted from the coupler end

FXC Disk R&D

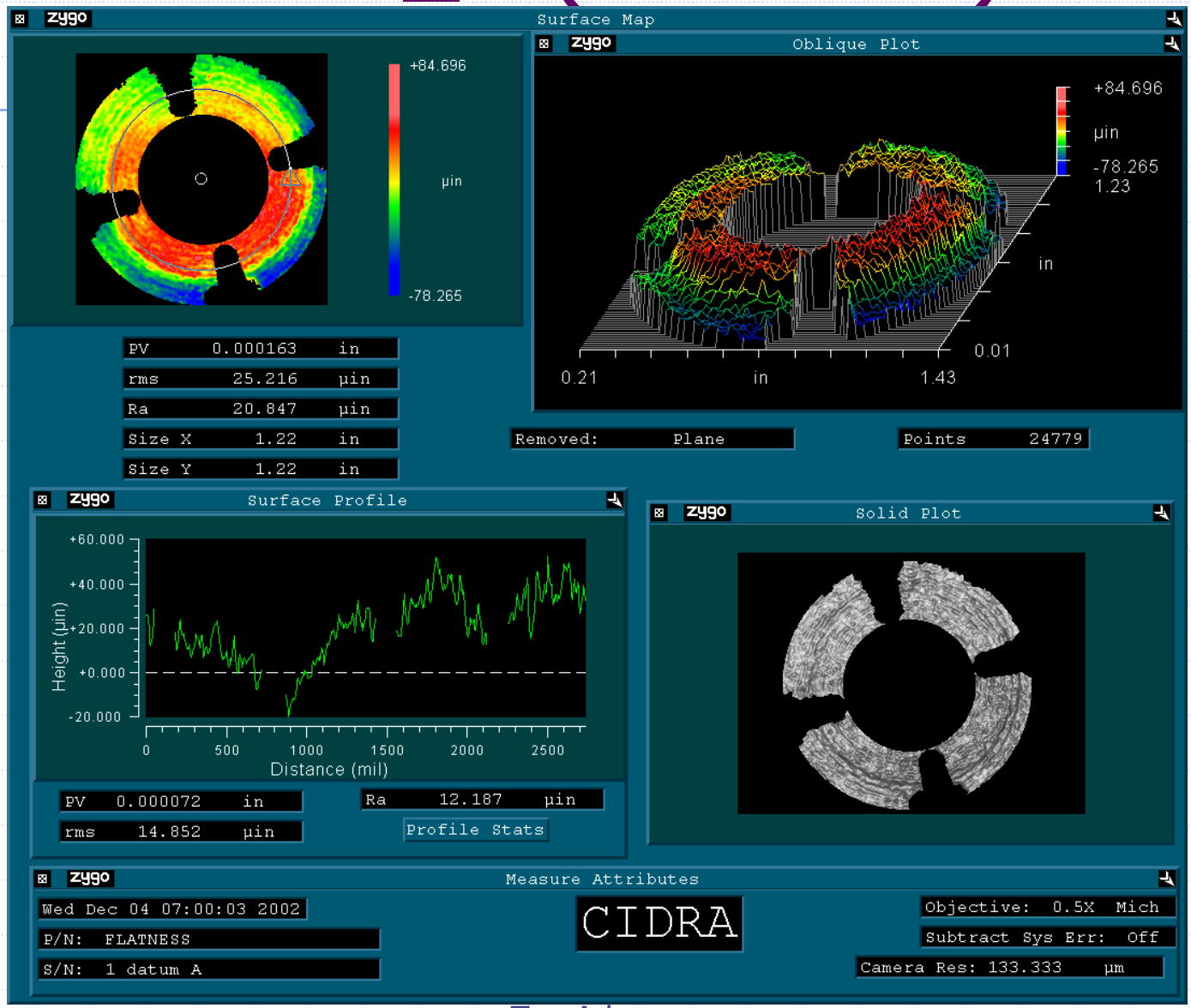
- 6 identical Disk#2 from HDDS cell table are ordered from our two major vendors (Medco and LaVezzi)
- 6 Disk#2 are received from Medco on November 25, 2002
- LaVezzi disks are due the first week on January 2003
- The QC conducted on 6 Medco disks:
  - 2 of the disks were sent to a vendor for Zygo Flatness measurements
  - 2 of the disks were sent to Mechanical QC lab for CMM measurements
  - 2 of the disks were measured with RF
- We are trying to identify more vendors for disk manufacturing

Flatness Measurements

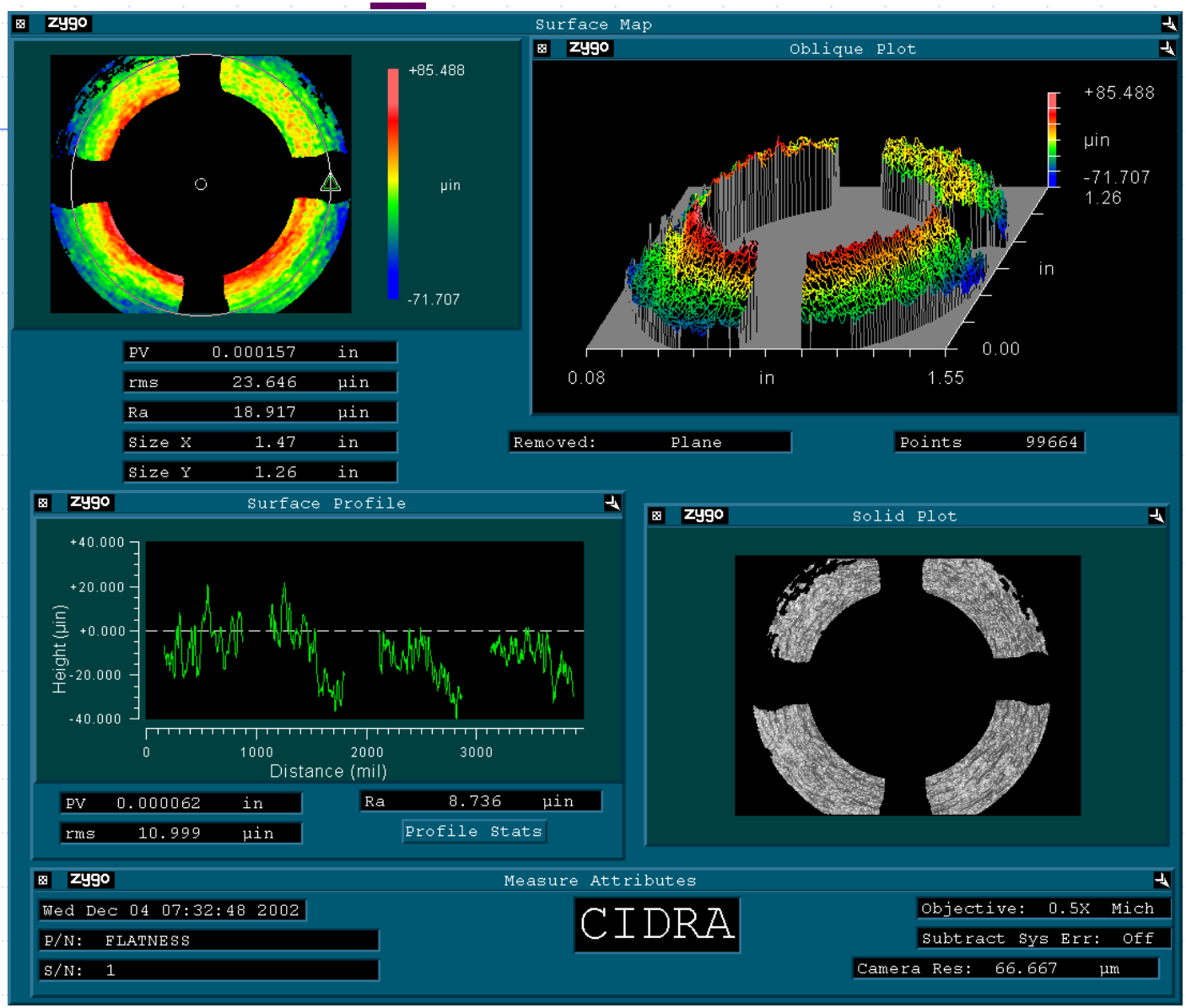
- Flatness Measurements are done with a Zygo New View 5000 3-D Surface laser interferometer (Vertical Resolution: 0.1 nm; Lateral Resolution: 0.64 micron)
- 2 identical FCX disks and 5 diffusion bonding dummy (w/o iris) test disks were sent for measurements

- Summary of the datum A flatness:
  - FXC Disk#2_1: Flatness(0.0001”)=0.000157”=3.8 micron
  - FXC Disk#2_2: Flatness(0.0001”)=0.000128”=3.4 micron
  - Dummy#1: Flatness(0.0001”)=0.000122”=3.0 micron

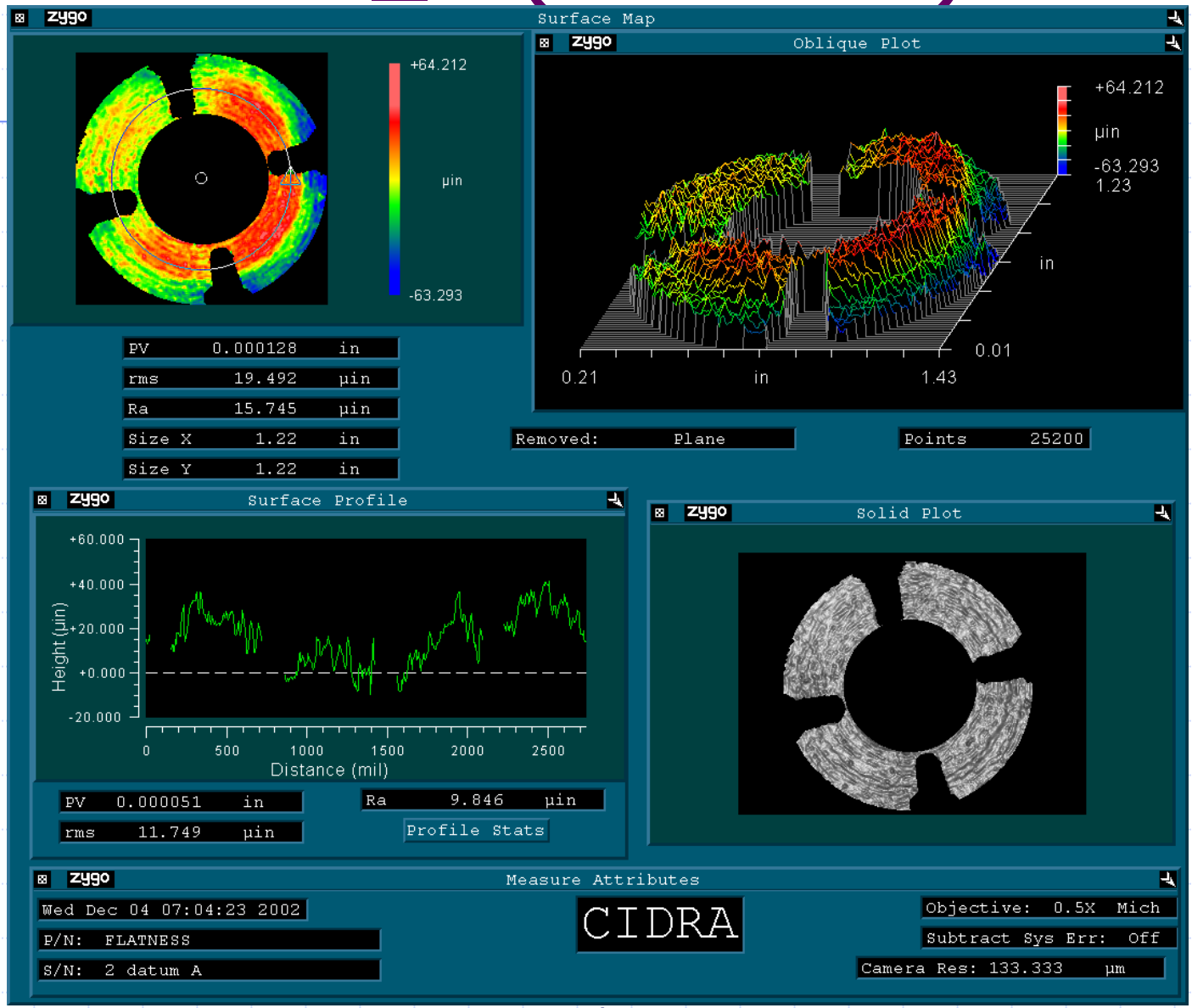
FXC Disk#2_1 (Datum A)



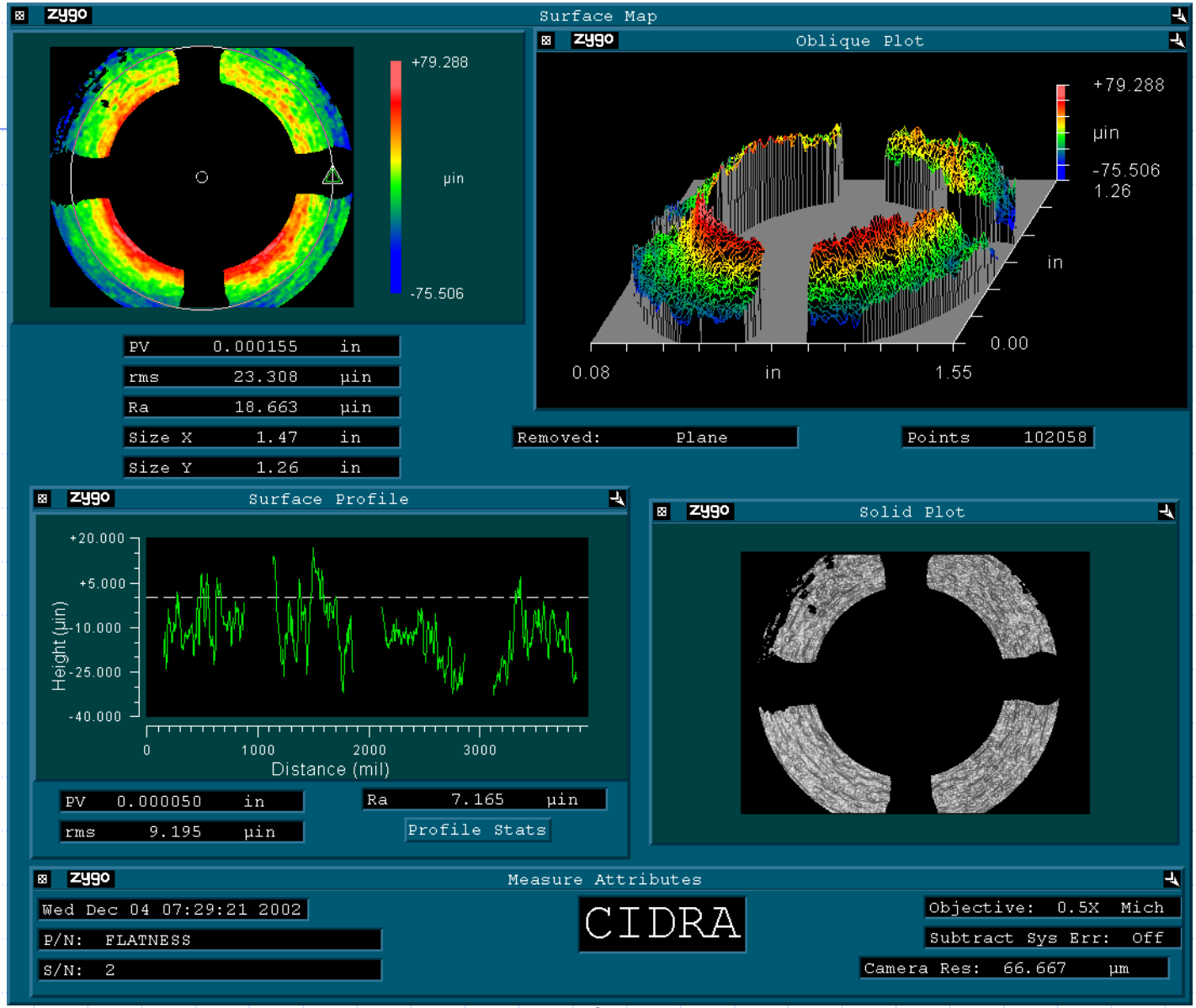
FXC Disk#2_1


zygo
Surface Map
+85.488
µin
-71.707
PV 0.000157 in
rms 23.646 µin
Ra 18.917 µin
Size X 1.47 in
Size Y 1.26 in
Oblique Plot
+85.488
µin
-71.707
1.26
in
0.00
0.08
in
1.55
Removed: Plane
Points 99664
Surface Profile
+40.000
+20.000
+0.000
-20.000
-40.000
Height (µin)
0
1000
2000
3000
Distance (mil)
PV 0.000062 in
rms 10.999 µin
Ra 8.736 µin
Profile Stats
Solid Plot
Measure Attributes
Wed Dec 04 07:32:48 2002
P/N: FLATNESS
S/N: 1
CIDRA
Objective: 0.5X Mich
Subtract Sys Err: Off
Camera Res: 66.667 µm

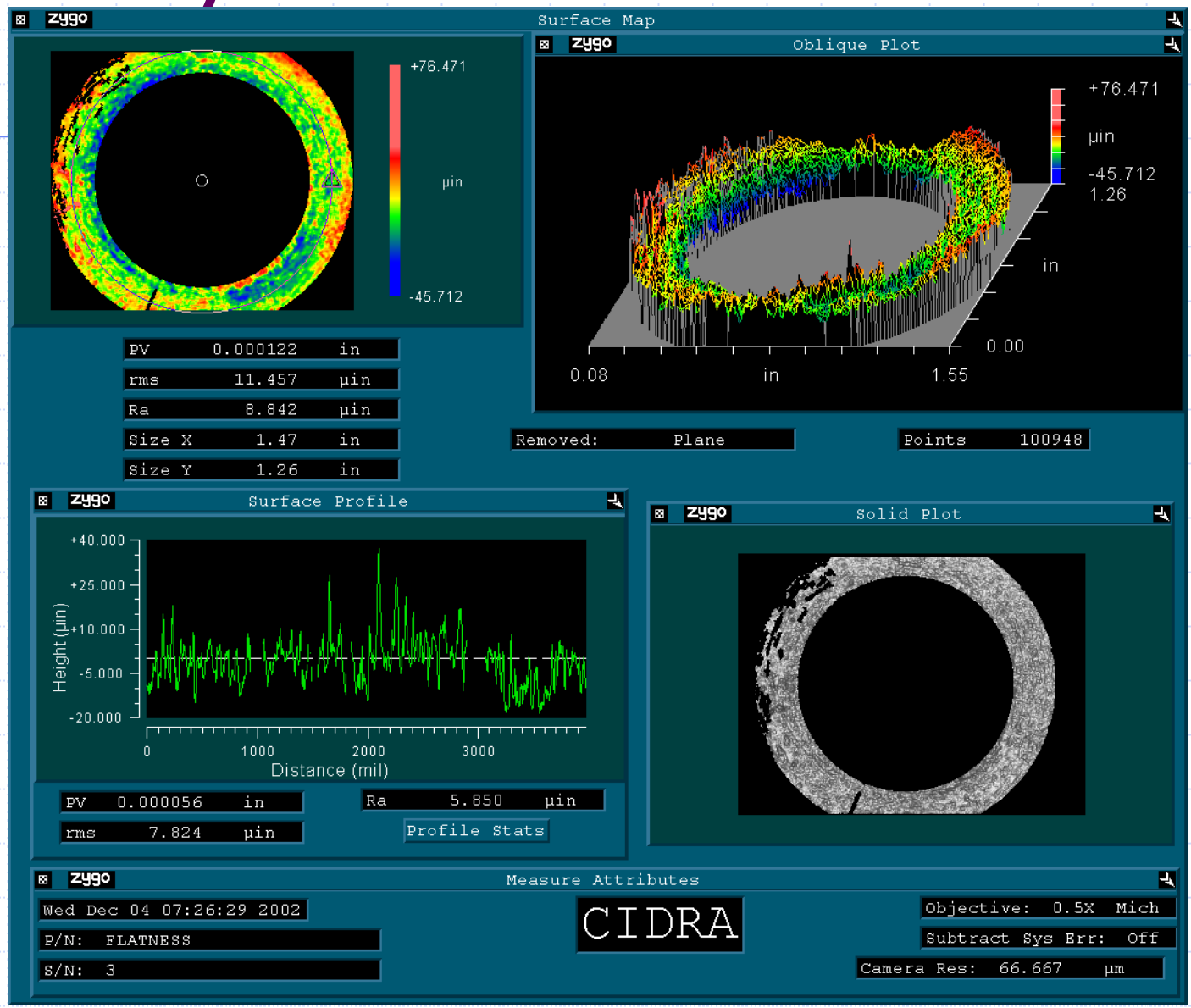
FXC Disk#2_2 (Datum A)



FXC Disk#2_2


zygo
Surface Map
+79.288
µin
-75.506
PV 0.000155 in
rms 23.308 µin
Ra 18.663 µin
Size X 1.47 in
Size Y 1.26 in
Oblique Plot
+79.288
µin
-75.506
1.26
in
0.00
0.08
in
1.55
Removed: Plane
Points 102058
Surface Profile
+20.000
+5.000
-10.000
-25.000
-40.000
Height (µin)
0
1000
2000
3000
Distance (mil)
PV 0.000050 in
rms 9.195 µin
Ra 7.165 µin
Profile Stats
Solid Plot
Measure Attributes
Wed Dec 04 07:29:21 2002
P/N: FLATNESS
S/N: 2
CIDRA
Objective: 0.5X Mich
Subtract Sys Err: Off
Camera Res: 66.667 µm

Dummy Disk


zygo
Surface Map
+76.471
µin
-45.712
PV 0.000122 in
rms 11.457 µin
Ra 8.842 µin
Size X 1.47 in
Size Y 1.26 in
zygo
Oblique Plot
+76.471
µin
-45.712
1.26
in
0.00
0.08
in
1.55
Removed: Plane
Points 100948
zygo
Surface Profile
+40.000
+25.000
+10.000
-5.000
-20.000
Height (µin)
0
1000
2000
3000
Distance (mil)
PV 0.000056 in
rms 7.824 µin
Ra 5.850 µin
Profile Stats
zygo
Solid Plot
zygo
Measure Attributes
Wed Dec 04 07:26:29 2002
P/N: FLATNESS
S/N: 3
CIDRA
Objective: 0.5X Mich
Subtract Sys Err: Off
Camera Res: 66.667 µm

CMM QC on FXC Disks

- The brand name of the CMM is Cordax. It has a 2.5-micron accuracy
- The measurements were done during two days
- No actual timing of the actual measurement process was recorded, but is it reported by the QC lab that it is very time consuming to QC these parts due to HOM holes & radiuses
- The temperature in the QC laboratory is usually stable and monitored within +- 2 degree F and it was recorded as 74~75 degree F in the room during the measurements for both days

CMM QC on FXC Disks

FXC Disk2_3:

Dim2a=
Nominal: 10.795mm (+-5 micron)
Measured: 10.795mm
Deviation: 0

Dim2b=
Nominal: 22.616mm (+-5 micron)
Measured: 22.618mm
Deviation: +2 micron

Dim t=
Nominal: 4.536mm (+-5 micron)
Measured: 4.534mm
Deviation: -2 micron

OD=
Nominal: 61.00mm (+-25 micron)
Measured: 61.02mm
Deviation: +20micron

Thickness=
Nominal: 12.928mm (+-50 micron)
Measured: 12.926mm
Deviation: 2 micron

Parallelism=
Nominal: 0 (+5 micron, -0)
Measured: 12.5 micron

CMM QC on FXC Disks

FXC Disk2_3:

HOM(4) ID=
Nominal: 6.50mm (+-50 micron)
Deviation: First:+7.5micron
Second:+2.5micron
Third:+2.5micron
Fourth:+7.5micron

HOM(4) Dim w=
Nominal: 3.159mm (+-12.5 micron)
Deviation: First:-73micron
Second:-71micron
Third:-88micron
Fourth:-83micron

HOM(4) Dim w1=
Nominal: 4.856mm (+-5 micron)
Deviation: First:+119micron
Third:+115micron

HOM(4) Dim d=
Nominal: 8.750mm (+-5 micron)
Deviation: First:-20micron
Second:-10micron
Third:-18micron
Fourth:-15micron