ATF2

Magnets

Report on the mechanical measurements of ATF2 “Final Doublet” magnets and how they relate to their measured multipoles and the predicted IP beam spot size

Cherrill Spencer, SLAC

Member of ATF2 Magnet Team

With fine assistance of SLAC Mechanical Technicians,

Magnetic Measurement Group & John Amann

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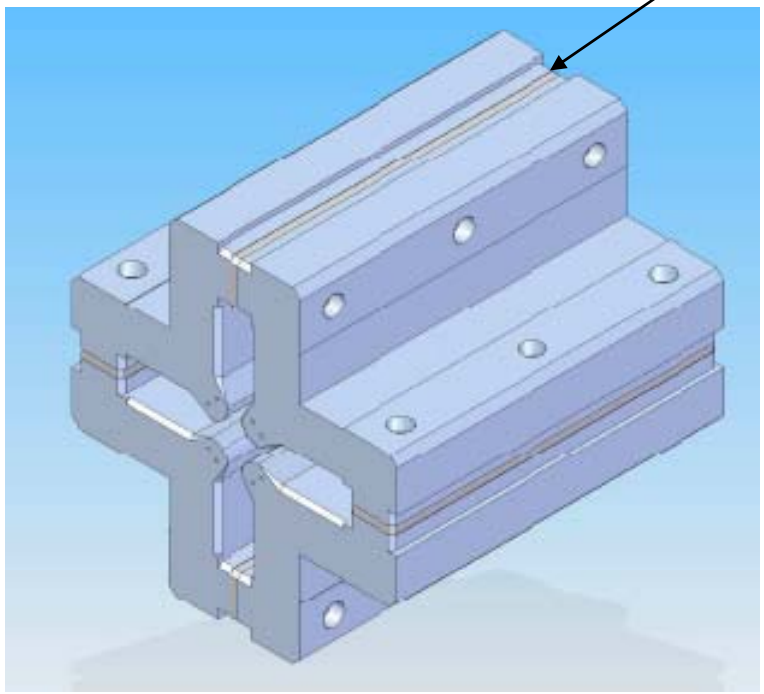
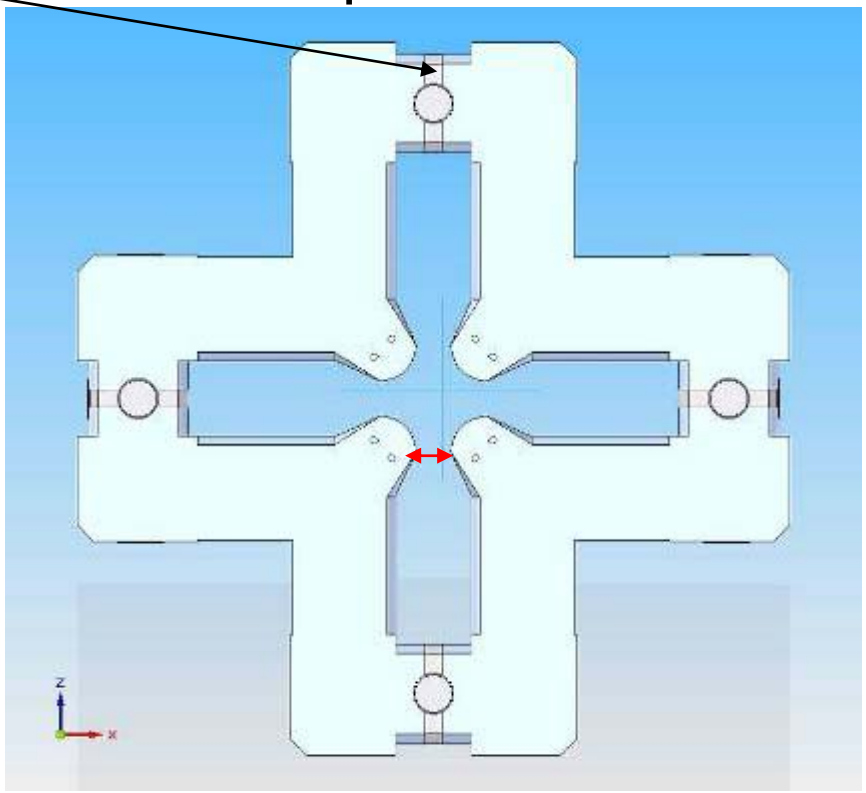
Drawings of the modified core with ground shims in place, to increase aperture to 50mm





Sextupole component is very sensitive to poletip being at wrong radius or the poletip being offset "azimuthally"

INITIAL GOAL :Adjacent pole distances (red arrow above) "gaps" adjusted, by moving quadrants, to be same to +/- 0.013mm. Many efforts, but not possible to achieve this with 4 bore diameters & 8 gaps values simultaneously on both quads- see later

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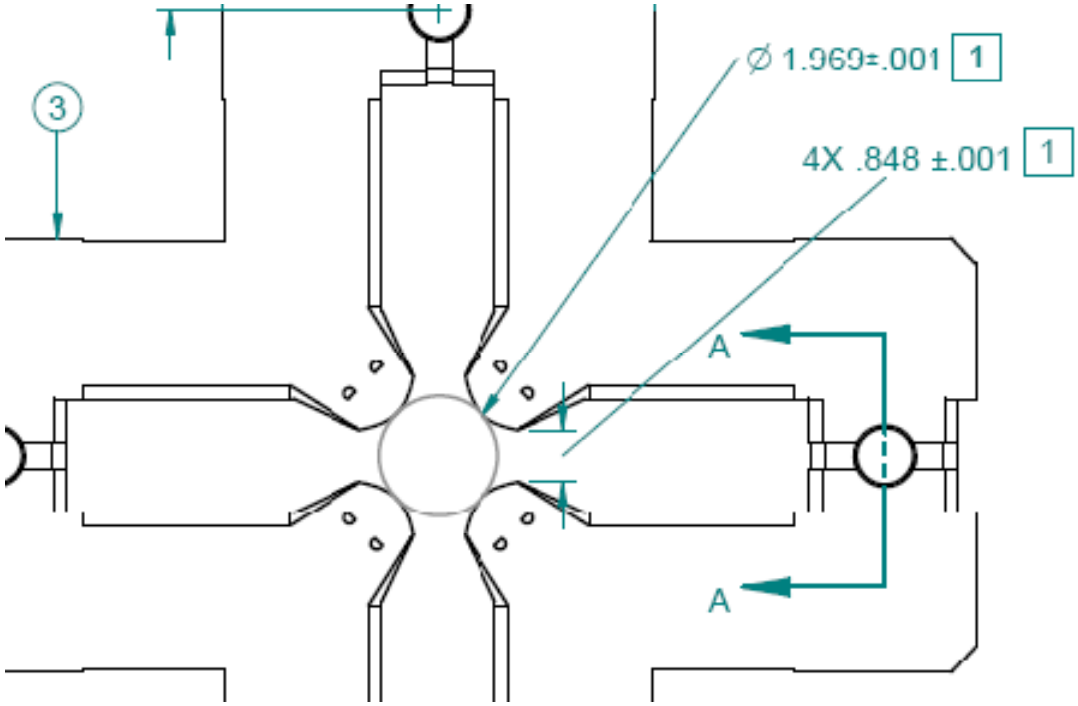
In order to achieve the very small multipoles : specification for the bore diameters and gaps between the ends of the adjacent hyperbolas

Units = inches



In fact the actual value of the gaps is less important than their being the same to within some value, +/-0.001” is typical mechanical tolerance for quads.

We predicted that to achieve the very small sextupole component requirement the equivalency of the gap values would need to be:

approx <+/- 0.0005”

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I designed some pole-side shims to reduce the introduced 12 pole. Shims have to be shorter than pole so can access end of hyperbolic poletip for QC of gaps

REV	DESCRIPTION	DWN	CHKR	APVD	DATE
1	ADDED DIMENSION .118	JA	CHKR	APVD	DATE

.38 (.38)

A

.124

.118

DETAIL A

ISO VIEW NOT TO SCALE

NOTES:

1. PLACE MAGNET YOKE QUADRANT WITH COIL ON SURFACE PLATE SO THAT POLETIP FACES UP.
2. USING A DIAL INDICATOR, MEASURE THE HEIGHT AT THE END OF ALL 4 POLETIP EDGES (DETAIL A) FROM THE TOP OF THE SURFACE PLATE.
3. ADD SHIMS BENEATH MAGNET YOKE QUADRANT UNTIL ALL 4 POLETIP EDGES ARE AT THE SAME HEIGHT TO WITHIN +/- .001". THIS WILL ENSURE THAT THE POLETIP IS ORIENTED CORRECTLY.
4. INSTALL ITEM 2 USING ITEM 3 AS SHOWN.
5. USING A DIAL INDICATOR, MEASURE DISTANCE AT BOTH ENDS OF THE MAGNET FROM CENTER OF POLETIP TO EDGE OF POLETIP SHIM AND ADJUST TO DIMENSION AS SHOWN.

ITEM	STOCK OR PART NO	TITLE OR DESCRIPTION	QTY
3		316 SS SHCS M4x10MM L	10
2	PF-490-900-17 R3	POLETIP SHIM	2
1	PF-490-900-09,10,11,12	QUADRUPOLE MAGNET QUADRANT	1

SCALE: 1:2 | DO NOT SCALE DRAWING | CAD FILE NAME: poletip shim installation.dft

NEXT ASSEMBLIES: SA-490-900-19

DIMENSIONING AND TOLERANCING IS IN ACCORDANCE WITH ASME Y14.5M-1994.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES: BREAK EDGES .005-.015 INTERNAL CORNERS R.015 MAX FRACTIONS ± --- DEC .xx± .01 .xxx± .001 .xxxx± --- ANGLE ± --- 63 ALL SURF

STANFORD LINEAR ACCELERATOR CENTER
U.S. DEPARTMENT OF ENERGY
STANFORD UNIVERSITY STANFORD, CALIFORNIA

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APPROVALS	DATE
ENGR John Amann	---
DWN John Amann	---
CHKR ---	---

1.97Q17.72

POLETIP SHIM ASSEMBLY

DRAWING NUMBER SA-490-900-18 | REVISION NUMBER 1 | C

SA-490-900-18 1 C | SH --- OF ---

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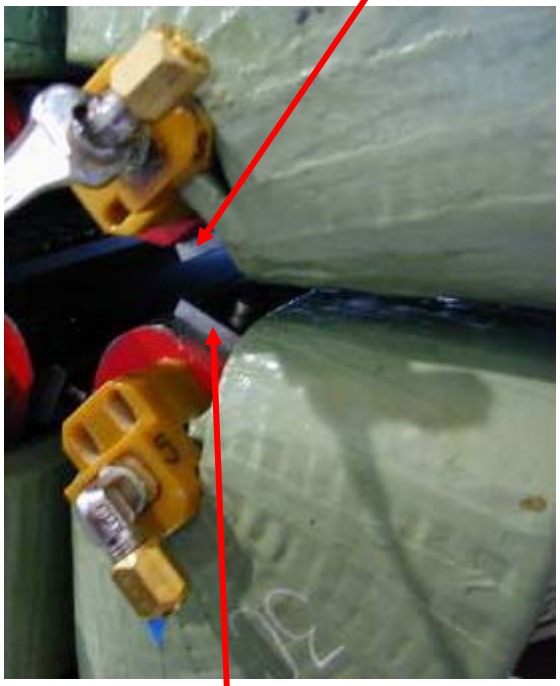
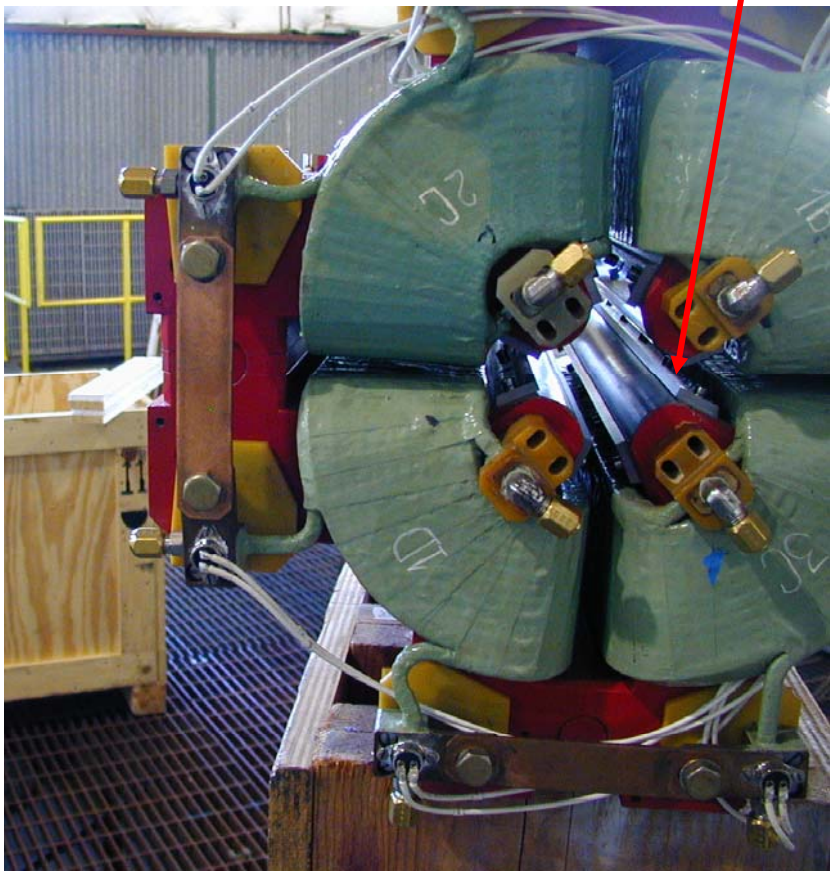
Photos showing the pole-side shims on QF1. They have been pinned into proper position.





These shims are a little shorter than the poles, so a gauge block can be inserted between the ends of the poletips, to measure the gap between them.

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Worked with mechanical technician to improve adjacent poles' & diameters' symmetries

- Dowel pin holes adjusted then main bolt

  [holding 4 quadrants together] torque settings adjusted iteratively, distances and aperture diameters re-measured, until best values achieved
- Tried several mechanical configurations, measuring multipoles after each try, repeated until we

  could not make the gap values get any closer to each other without hurting the diameters' equivalency
- Next 2 slides show mechanical measurements on QD0 over 7 months as we tried various techniques to reduce the 12 pole. Data show that if symmetry is not maintained sextupole will increase.

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Magnets

As we modified the quads' cores we repeatedly measured their adjacent pole gaps, their aperture diameters & their fields

PART NAME:	**QC3 quad for ATF2**				REC'D:	**1**		DATE:		**March 14, 2008**		
PF/SA NO.:		REV:			INSP'D:	**1**		INSPECTOR:		**T. Nakashima**		
ASSY/PROJECT:					ACC'D:			ENGINEER:		**C. SPENCER**		
WORK ORDER/CHARGE#:		SEQ ID:			REJ'D:			PHONE/EXT:		**3474**		
VENDOR:					NCR:	-		ROUTE TO:		**COIL**		
Measurement DATE –>		**8/21/07**		**9/4/07**		**9/18/07**		**9/28/07**		**3/7/08**		**3/14/08**
DIMENSIONS												
LEAD IN SIDE. INCHES		Measured by gauge blocks					Range					
POLE D-A "gap"		0.8507		0.8517		0.8531	in	0.8515		0.8513		0.8513
POLE C-B		0.8506		0.8523		0.8538	gap	0.8521		0.8522		0.8516
POLE A-B		0.8512		0.8503		0.8496	values	0.8506		0.8506		0.8519
POLE D-C		0.8508		0.8504		0.8494	9/28/07	0.8504		0.8512		0.8496
							0.0017					
OPPOSITE LEAD IN SIDE												
POLE C-D		0.8510		0.8508		0.8503		0.8509		0.8511		0.8503
POLE A-B		0.8507		0.8510		0.8494		0.8510		0.8510		0.8517
POLE B-C		0.8510		0.8525		0.8545		0.8529		0.8530		0.8523
POLE A-D		0.8509		0.8516		0.8534		0.8516		0.8511		0.8513
							0.0020					
DIAGONALS 1.969	**Quad measured** with rotating coil on 15 Oct 07: sext/quad =0.038%; 12pole/quad=0.17%											
LEAD IN SIDE							Range					
DIAG POLE A-C		1.9690		1.9691		1.9700	in	1.9691		-		1.9690
DIAG POLE B-D		1.9692		1.9700		1.9706	4 diags	1.9702		-		1.9702
							9/28/07					
OPPOSITE LEAD IN							0.0011					
DIAG POLE A-C		1.9692		1.9703		1.9710		1.9702		-		1.9701
DIAG POLE B-D		1.9692		1.9701		1.9708		1.9700		-		1.9680

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As we modified the quads' cores we repeatedly measured their adjacent pole gaps, their aperture diameters & their fields

PART NAME:	**QC3 quad for ATF2 (became QD0)**				REC'D:	**1**		DATE:		**March 19, 2008**		
PF/SA NO.:		REV:			INSP'D:	**1**		INSPECTOR:		**T. Nakashima**		
ASSY/PROJECT:					ACC'D:			ENGINEER:		**C. SPENCER**		
WORK ORDER/CHARGE#		SEQ ID:			REJ'D:			PHONE/EXT:		**3474**		
VENDOR:					NCR:	**-**		ROUTE TO:		**COIL**		
Measurement DATE->	**3/17/08**		**3/19/08**	**4/16/08 on CMM**								
DIMENSIONS												
LEAD IN SIDE INCHES		Range		Range								
POLE D-A	0.8508	in	0.8508	in	0.85137							
POLE C-B	0.8512	gap	0.8512	gap	0.85103							
POLE A-B	0.8523	values	0.8524	values	0.85130							
POLE D-C	0.8503	3/19/08	0.8503	4/16/08	0.85176							
		0.0021		0.0007								
OPPOSITE LEAD IN SIDE		:0.053mm		: 0.018mm								
POLE C-D	0.8506		0.8507		0.85079							
POLE A-B	0.8522		0.8523		0.85105							
POLE B-C	0.8518		0.8518		0.85141							
POLE A-D	0.8507		0.8507		0.85170							
		0.0016		0.0009		Pole-side shims not installed on 20 Mar 08						
DIAGONALS 1.969			**Quad measured** with rotating coil on 20 Mar 08: sext/quad =0.055%; 12pole/quad=0.17%									
LEAD IN SIDE		Range		Range								
DIAG POLE A-C	1.9696	in	1.9695	in	1.96933							
DIAG POLE B-D	1.9694	4 diags	1.9695	4 diags	1.96988							
		3/19/08		4/16/08								
OPPOSITE LEAD IN		0.0004		0.0009								
DIAG POLE A-C	1.9699		1.9699		1.96992							
DIAG POLE B-D	1.9693		1.9696		1.96906	Pole-side shims were installed on 23 Apr 08						
			Quad measured with rotating coil on 23 Apr 08: sext/quad =0.0255%; 12pole/quad=0.036%									

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Final Multipole Measurements on both FD quads at r=1cm, in %

Magnet Name	Sextupole/ quad	Octupole/quad	10pole/quad	12pole/quad	20pole/quad
Tolerance (tightest)*	<0.03	<0.025	<~0.01	<0.05	<0.12
QD0 at 132.2 amps	0.0255	0.0052	0.007	0.036	0.0027
QF1 at 77.5 amps	0.0274	0.0058	0.0128	0.036	0.0027

* Multipole tolerances arrived at by many iterations between magnet engineer and beam dynamics experts. E.g. original sextupole tolerance was 0.0053%, too small to be measured even. Hope was that if kept below above quoted tolerances then would have acceptable beam spot size.

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Magnets

But have to include the values of the angles of the poles of all the multipoles in the simulations. List first south pole relative to the horizontal axis, rot coil not set correctly for 0º

- Field Harmonics for QF1
- Magnet Current for Quad Main = 77.53 +- 0.019081 A
- Harmonics given at R = 0.010000 m
- Coil Radius, Rcoil = 0.019837 m
- Main Harmonic N = 2 *(make correction for pole angles before use data)*

n	BLn (Tm)	sigBLn (Tm)	THspole (deg)	sigTH (deg)	BLn/BLN (%)	sBLn/BLN (%)
1	8.2761e-04	6.9682e-07	-94.86	0.02	2.43516	0.00205
2	3.3986e-02	7.9744e-07	37.49	0.00	100.00000	0.00332
3	9.3009e-06	2.6127e-08	24.47	0.06	0.02737	0.00008
4	1.9530e-06	3.1846e-08	-28.92	0.26	0.00575	0.00009
5	4.3326e-06	8.8046e-09	8.77	0.02	0.01275	0.00003
6	1.2085e-05	8.5023e-09	-24.58	0.01	0.03556	0.00003
7	2.1640e-07	2.0596e-09	-22.04	0.06	0.00064	0.00001
8	6.0286e-08	1.7915e-09	9.58	0.15	0.00018	0.00000
9	2.2724e-07	6.5936e-10	-17.50	0.04	0.00067	0.00000
10	9.2182e-07	5.9612e-10	1.24	0.00	0.00271	0.00000

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Have shown that the sextupole size varies with the relative positions of the 4 poletips. The more they are asymmetric the larger the sextupole component.

- The spot size at the IP is very sensitive to the sextupole components in QD0 and QF1
  - The QD0's unwanted sextupole is mostly a skew sextupole, it affects the spot size more than a normal sextupole would
- Also: the pole-side shims cannot be placed perfectly symmetrically and they tend to affect the sextupole's size, even when the pole gaps are quite symmetric.
- See the next slide from Glen White

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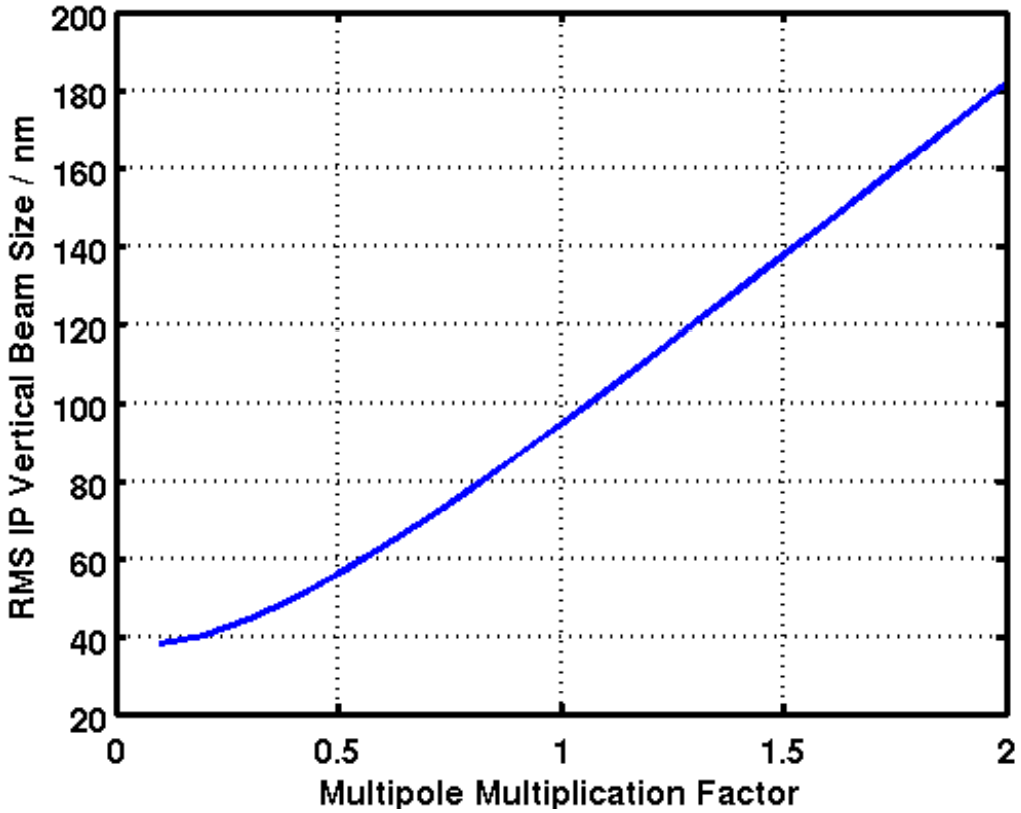
Magnets

IP Beam size Vs. Scaled Fraction of Measured QF1/QD0 Multipoles. Have included the multipoles of the 3 dipoles & 5 sextupole (no other errors in lattice)



This is Lucretia's prediction for present measured multipoles. If sextupole increases when quad is split in half and re-assembled then the spot size will increase per blue line.

- E.g. % Multipole / QD0 strength @ 1cm (sext -> 20-pole):
  - [0.02549 0.00524 0.00717 0.03603 0.00056 0.00003 0.00037 0.00271]*factor

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So is very important that the FD quads be re-assembled after they've been split according to a set of instructions worked out by SLAC's senior mechanical technician

- I wrote out these instructions, with illustrations, in a PowerPoint file and sent them to Terunuma-san and others a few weeks ago.
- If these instructions are not followed I predict the two halves of the quads will not go back into their previous positions (by up to ~ 0.05mm) with the possible result that the sextupole components will be even larger!
- Next 5 slides show most critical instructions

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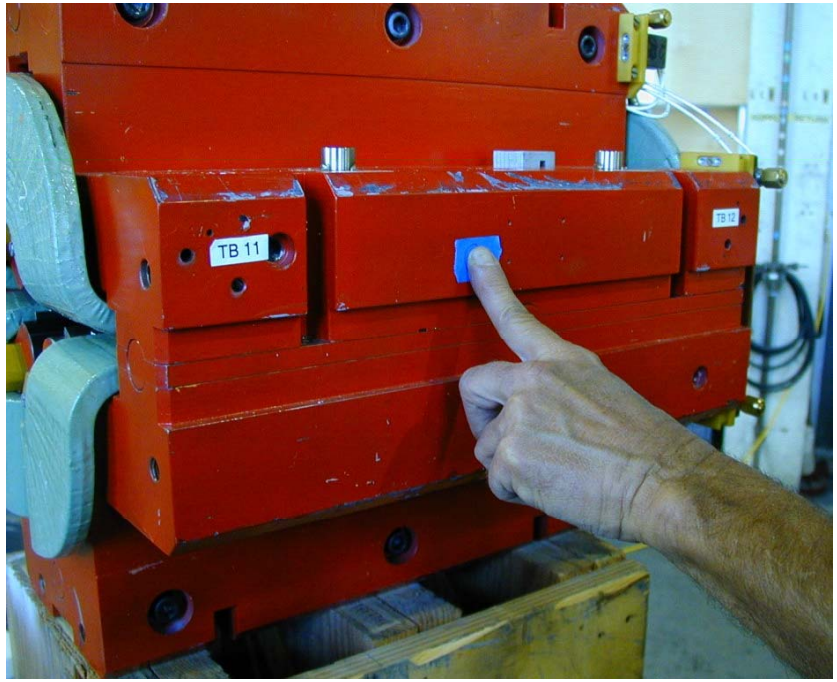
Magnets

Instructions for lowering & positioning the top of QD0 onto its lower half.



YOU MUST FOLLOW THESE INSTRUCTIONS on QD0 ELSE YOU WILL NOT ACHIEVE THE REQUIRED SYMMETRY OF THE 4 POLETIPS!

Stand on the side with the blue dot (might be easier to have 2 people)

Lower the top gently with the crane. The 6 hanging bolts should help guide the top into the correct position over the bottom.

Slowly match the slots in the top with the dowel pins in the bottom, *pause when top's mating surface is about 4mm above the bottom's*

With left forefinger press on the blue dot (see photo) so top is pushed away from you until it is stopped by the bolts, then lower the rest of the way *keeping pressure on the blue dot until top is fully down!*

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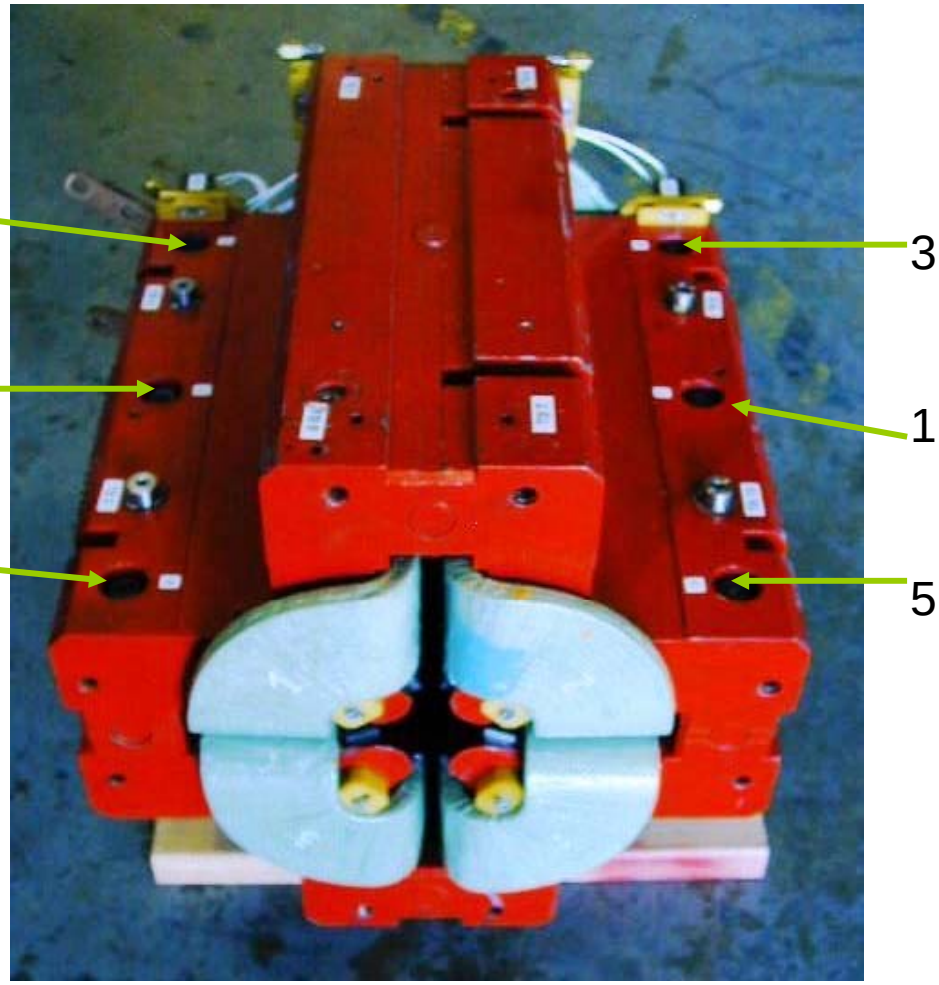
Magnets

Order in which 6 vertical bolts should be tightened on QD0



When the top half is back in place (having pushed on the blue dot as described on previous slide) : screw on the nuts on the bottom of the 6 bolts in the order shown on the left (1,2,3 etc) until they are finger-tight.

Then use a calibrated torque wrench to tighten the 6 bolts in the same order to 13.6 Newton-meters.

Then, in same sequence tighten all bolts to 47.5 N-m

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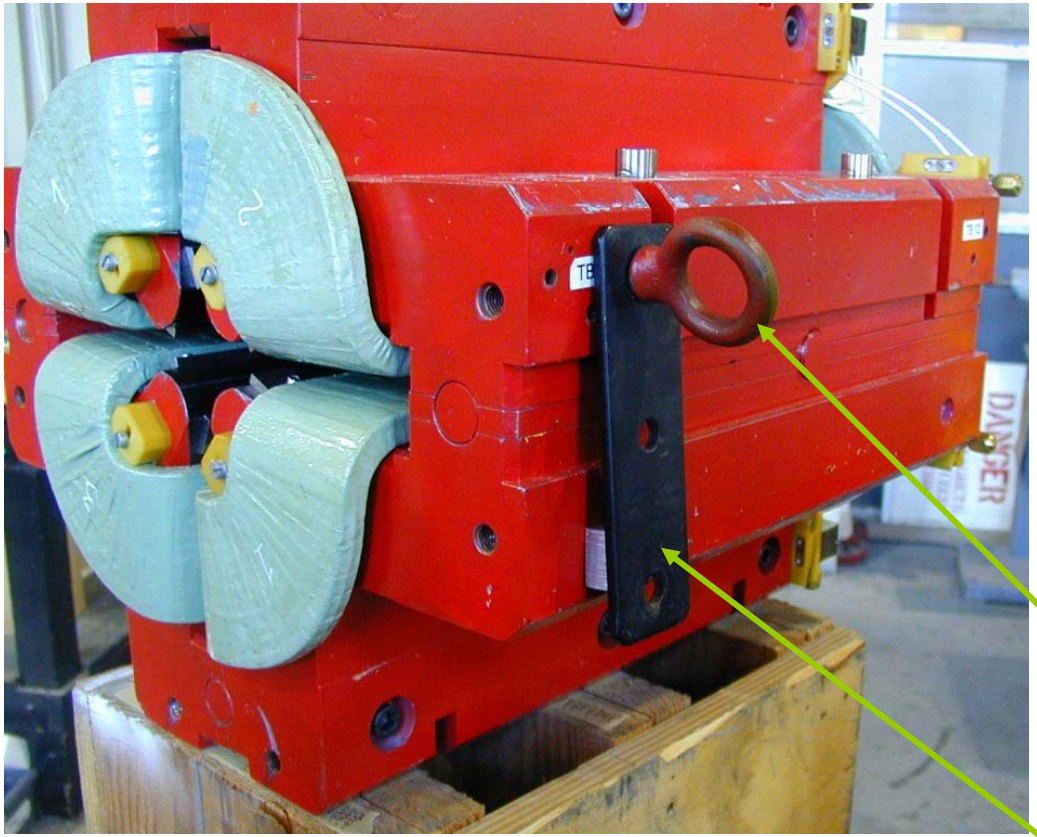
Magnets

Instructions for lowering & positioning the top of QF1 onto its lower half. Pg 1/2



Stand on the side with the TB9 & TB10.
Lower the top gently with the crane. The 6 hanging bolts should help guide the top into the correct position over the bottom.
Slowly match the slots in the top with the dowel pins in the bottom and let top half rest of the bottom.
Lightly screw an M12 eyebolt through the provided black plate into the hole below the “TB11” white label. Place the provided Al spacer as shown in the photo.

Instructions continued in next slide

ATF2

Magnets

Instructions for lowering & positioning the top of QF1 onto its lower half. Pg 2/2

Turn the eye bolt clockwise and the top half will be pulled towards you (remember the vertical bolts are loose).

How much to turn the eyebolt and how far to pull the top are determined by measuring the position of the beampipe in the aperture.

Assuming the OD of the BPM is exactly 48mm [should be measured before inserting it] the goal is to have a 1.01 to 1.02mm gap between each poletip and the closest surface of the beampipe.

Turn the eyebolt by hand only and measure above gaps, repeat until gaps have desired values (measure with gauge blocks) at both ends. May have to untwist the eyebolt some to get desired symmetry. When achieved, tighten the 6 bolts-see next page for order etc

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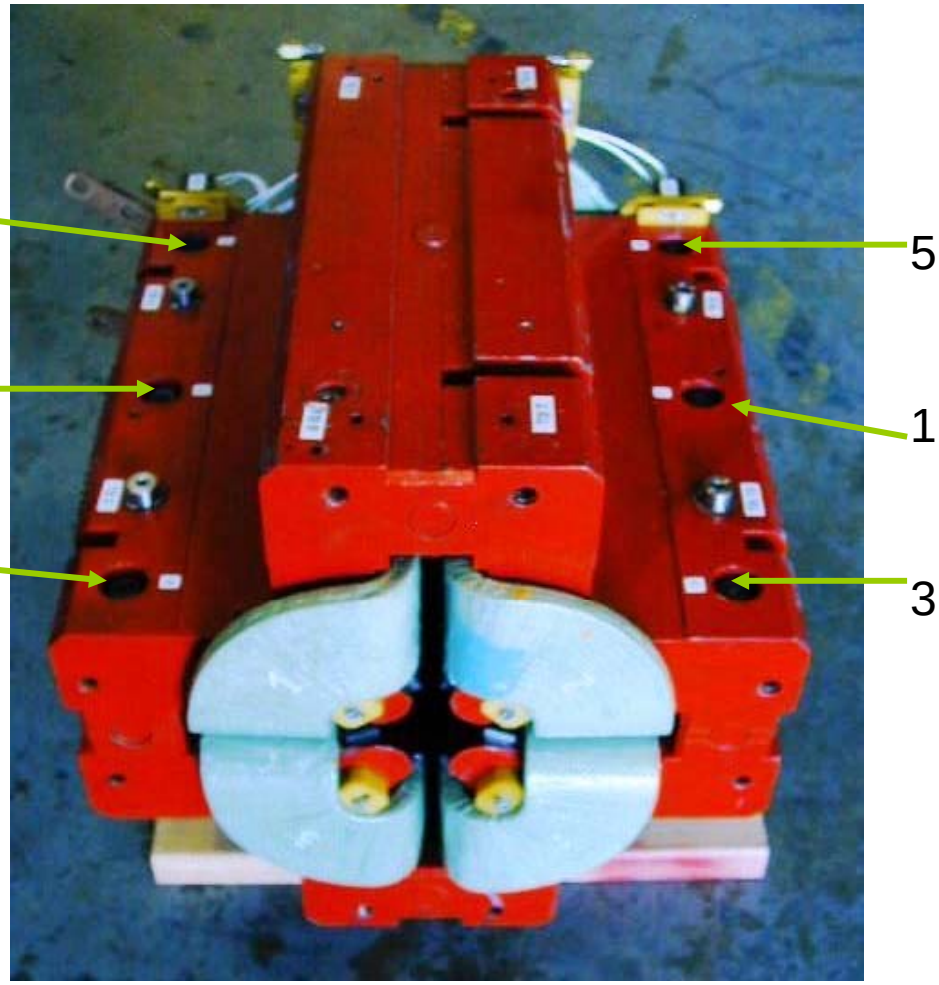
Magnets

Order in which 6 vertical bolts should be tightened on QF1



When desired symmetry of beampipe in aperture achieved, put the nuts on the 6 bolts and turn them *finger tight* in the order shown in photo.

Then tighten them to 20.3 N-m in order shown.

Then tighten them to 40.7 N-m in order shown.

Last: remove the black plate, spacer & eyebolt

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Last steps of instructions for re-assembling both QD0 and QF1: need to re-measure the diameters and the gaps to check their asymmetries have not worsened

- *But the S-BPM's pipe is in the aperture and so one cannot measure the diameters with gauge blocks. So I came up with a scheme to use the pipe as a measuring tool:* After the 6 vertical bolts have been tightened to the specified torques:
  - measure the spaces between the beampipe(47mm) and the poletips (should be 1.51-1.52mm). This step works only if the beampipe is truly circular, consistently 47mm and is sitting exactly at the center of the quad's aperture– how to ensure this???
    - First need to measure the pipe with a CMM to check its OD is really 47 +/- 0.01mm
    - I want to hold the pipe in the center with a specially made sleeve (only a few cm long) that by its dimensions and by it touching all 4 poletips will force the pipe to be centered.
  - Measure the adjacent poletip gaps. Compare them to the values measured before splitting the quad and decide if they are still within tolerance. See provided tables for diameter and gap values measured at SLAC, LAPP and KEK (before splitting the quads)
  - Send measurements to Cherrill Spencer by e-mail ASAP so she can judge if the quads are mechanically symmetric enough before quads put on movers.

Measured Diameters and Adjacent Pole Gaps on QF1: final values measured on a CMM at SLAC & gauge blocks at LAPP and KEK, no splitting occurred yet

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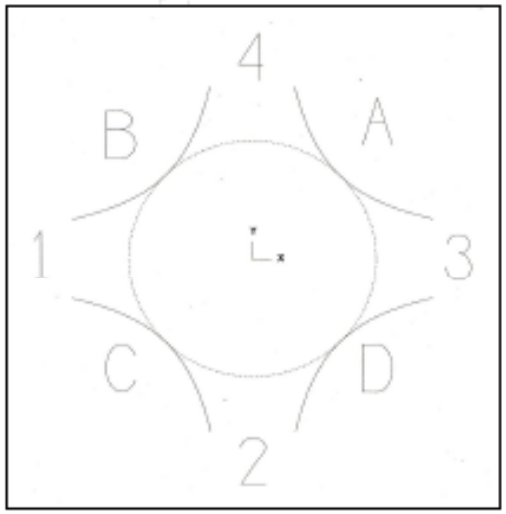
The 4 diameters are within 0.00073" [0.0185mm] of each other- this is very good.

But the gaps vary by up to 0.00476", this is ~4 times the preferred variation. We tried many different bolt torque settings to reduce this variation but could not manage it AND keep the diameters within 0.001".



The diameters and gaps in the table were measured on a CMM, precise to 0.00001".

These values agreed with our SLAC gauge block measurements, precise to 0.0001" [0.00254mm].

Units=Inches

Side	Pole Dist A-C	Pole Dist B-D	Gap 1	Gap 2	Gap 3	Gap 4
Downstream End (+Z)	1.96975	1.97028	0.84895	0.85155	0.85360	0.85062
Upstream End (-Z)	1.97016	1.96955	0.84858	0.85141	0.85334	0.85114

Units= mm

SLAC data

LAPP data

KEK data

No-lead end Downstream	50.032	50.045	21.563	21.629	21.681	21.606
	50.03	50.07	21.57	21.62	21.68	21.60
	50.03	50.07	21.57	21.63	21.68	21.60
Lead end Upstream	50.042	50.027	21.554	21.626	21.675	21.619
	50.03	50.03	21.562	21.62	21.66	21.62
	50.03	50.02	21.56	21.62	21.66	21.62

After air shipping to France; to KEK, gaps measured again with gauge blocks precise to 0.01mm

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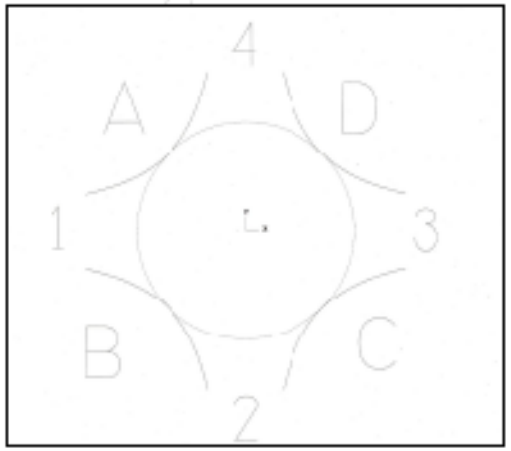
Measured Diameters and Adjacent Pole Gaps on QD0: final values measured on a CMM at SLAC and with gauge blocks at LAPP, at KEK, no splitting yet

The 4 diameters are within 0.00086" of each other- this is very good.

The gaps vary by up to 0.00091", this is better than the preferred variation of +/-0.0005". The sextupole is a *little* less in QD0 than in QF1. Indicating other factors (?) are contributing to the sextupole's size.



The diameters and gaps in the table were measured on a CMM, precise to 0.00001". These values agreed with our gauge block measurements , precise to 0.0001" [0.00254mm].

Units = inches

Side	Pole Dist A-C	Pole Dist B-D	Gap 1	Gap 2	Gap 3	Gap 4
Downstream End (+Z)	1.96992	1.96906	0.85141	0.85105	0.85170	0.85079
Upstream End (-Z)	1.96933	1.96988	0.85130	0.85103	0.85176	0.85137

NOTE-names of poles, A,B,C,D are in different positions on QD0 to QF1.

Units = mm
SLAC data
LAPP data
KEK data

No-lead end Downstream	50.036 50.04 50.03	50.014 50.02 50.02	21.626 21.62 21.62	21.617 21.61 21.62	21.633 21.64 21.63	21.610 21.61 21.62
Lead end Upstream	50.021 50.02 50.01	50.035 50.03 50.03	21.623 21.63 21.62	21.616 21.60 21.60	21.635 21.63 21.63	21.625 21.62 21.63

After air shipping to France, to KEK, gaps measured again with gauge blocks precise to 0.01mm