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QRI (Q1) Table 2I(e) GOLDEN MAGNETS

Expected values of body harmonics in 130 mm Insertion Quadrupoles
GOLDEN QRI (Q1) at 5000 A :

[<bn> = mean, d(bn) = uncertainty in mean, sig(bn) = sigma for bn]

n	<bn>	d(bn)	sig(bn)	<an>	d(an)	sig(an)
1	0	10.	10	0	0	10
2	0.	0.5	2.4	0.0	0.1	1.2
3	0	1.0	.6	0.0	0.3	.7
4	0.	0.3	.6	0.0	0.1	.5
5	-1.2	0.5	.5	0.0	0.4	.6
6	0.0	0.12	.11	0.0	0.09	.12
7	-0.2	.05	.05	0.0	0.03	.12
8	0.0	0.04	.05	0.0	0.05	.09
9	0.45	0.05	.03	0.0	0.03	.03

Expected body harmonics at 660 A
(same as above except for b5 and b9)

5	-4.2	2.0	.5
9	0.3	0.2	.03

Expected body harmonics at 1450 A
(same as above except for b5 and b9)

5	-1.7	1.5	.5
9	-0.3	0.2	.03

Expected values of harmonics in LEAD END at "ALL" currents (Unit-m)

n	<Bn>	d(Bn)	sig(Bn)	<An>	d(An)	sig(An)
1	0	0	0	0	0	0
2	0.0	0.1	0.7	0.0	1.	2.
3	0.0	0.3	.3	0.0	0.4	.8
4	0.0	0.1	.3	0.0	0.3	.4
5	4.6	.5	.3	-1.5	0.5	.2
6	.0	0.01	.04	0.0	0.06	.06
7	0.0	0.04	.05	0.0	0.02	.01
8	0.0	0.04	.05	0.0	0.02	.02
9	-0.5	.05	.02	0.2	.05	.03

Expected values of harmonics in RETURN END at "ALL" currents (Unit-m)

n	<Bn>	d(Bn)	sig(Bn)	<An>	d(An)	sig(An)
1	0	0	0	0	0	0
2	0.0	0.3	1.8	0.0	0.7	1.
3	0.0	0.1	.2	0.0	0.1	.3
4	0.0	0	.25	0.0	0.2	.2
5	1.	0	.6	0.0	0.1	.1
6	0.0	0.06	.03	0.0	0.06	.02
7	0.0	0.01	.02	0.0	0.02	.05

8	0.0	0.03	.03		0.0	0.01	.02
9	-.1	0	.03		0.0	0.04	.01

Notes:

0. X in 1st/2nd column of the following lines means that this argument is either not valid any more or not relevant any more. These lines are left here for historical reasons. Similarly, a question mark in the 1st/2nd column of a line would mean that it is under review.

X 1. Only two 130 mm quadrupoles have been built and tested so far. X The main purpose of these tables is to come up with a resonable set X of mean and sigma values of field harmonics. The obvious statement X is that "though the mean and sigma can be computed from two magnets", X portraying them as the "reasonable set" for a large number of magnets X is questionable.

X 2. To obtain a statistically better sigma values for body harmonics X in the 130 mm aperture quadrupoles, we use the sigma obtained X from the measured harmonics in the six identically built 80 mm X aperture quadrupoles QRB007-QRB012. We should actually expect a X lower sigma in 130 mm aperture quadrupoles as compare to 80 mm X because of the higher coil radius. For the harmonics in the ends X we shall use the measurements of the 130 mm aperture quadrupoles. X In the case of 80 mm quad, only one magnet (QRB009) has a z-scan X which could have been used here.

3. For obtaining systematic harmonics, we treat allowed and non-allowed terms differently. The allowed terms are the expected values after iteration. <b3> and <b7> are treated as the allowed harmonics. The systematic values of the other non-allowed harmonics are obtained by X taking the average of measurements in QRI001 and QRI002. These values can not be considered very reliable because of the poor statistics.

4. The above table generally represent harmonics before "shimming". However, an exception is granted to harmonics <b3> and <b7> where the magnetic tuning shims (together with the asymmetric midplane shims) are considered as an integral part of the design.

X 5. An item in () means that it is either inserted after the 6/2/93 X meeting or needs further examination. This number would be X the same in table 2(b) if it was merely inserted and different X if I have put my best guess. If item is still in () in table X 2(b), that means that the item is being currently examined.

X 6. The table 2.0 (made for Accelerator Physicists) will have only X two columns. The 2nd column will be absorbed in the 1st. At 5000 A, X the magnitude of the second column would be added to the magnitude X of the first column of this table to make the first column of the new table 2.0. The systematic values of the allowed harmonics at 660 A and at 1450 A will be determined by the measured current dependence in these harmonics in magnets QRI001 and QRI002.

X 7. A value of d(b9) = 0.15 is inserted in this table to represent the X uncertainty in b9. This is consistent with the way d(b5) = 1.5 unit X is arrived.

8. As per J. Wei's memo of 6/7/93 the <b7> = -0.45 (generated as a result of the midplane shim to correct <b3>) is rather large. A way to reduce that is to partly correct <b3> by midplane shim and partly by magnetic tuning shim. The sign of <b7> generated in the two methods is opposite. (see more in the next section for the new value of <b7>).

X 9. <b3> is changed because of the two reasons. (a) The numbers in Animesh's
X   memo of 6/7/93 indicate that the <b3> should be 1.9 instead of 1.5.
?   (b) Because of such a large value of <b3>, we consider that the tuning
?   shims are an integral part of the design to make remainder of the <b3>
?   zero. This creates ~+0.2 of <b7> which when added to <b7> = -0.45 from
?   the midplane shims gives a net <b7> = -0.25. (Note that this <b7> can
?   be further reduced, in principle, by changing the proportion of the
?   <b3> to be corrected by the midplane shims and by the tuning shims).

X   Note: We now make <b3> = 0.

10. Just as in 8 cm quadrupole, there is an uncertainty in b3 (as such and
    with the midplane and tuning shims added). d(b3) = 1.0 unit is inserted
    to represent these three terms. In the table 2.0 for accelerator
    physicists, we would thus use <b3> = 1. Similarly d(b7) = 0.1 unit is
    inserted so that it is consistent with the way d(b3) = 1 is obtained.
    The actual <b3> in the magnet will be removed by the tuning shims.

11. The values of a4 and b4 (like all other harmonics) are obtained by
    adding several 9" coil measurements.

12. Values for a1 are not given here. It is presumed that misalignment
    errors will predominate this harmonic. In any case this was not
    a measured harmonics in the magnets tested so far.

13. d(b1) = 10 was arrived from the estimated errors in coil length
    and similar parameters.

X 14. In the case of harmonics due to lead ends, Pat has provided the
X   computed values based on the expected change in the lead configuration.
X   Only the following harmonics have any significant change in the values:
X   b5, b9, a5 and a9. In table are the most likely case numbers. We will
X   not add column 2 to column 1 to create the column 1 of the table 2.0
X   for accelerator physicists. There is an unexplained <B5> of ~ 2 unit-m
X   and <A5> of ~2.5 unit-meter in the magnets QRI001 and QRI002. In his
X   estimates Pat has assumed that this unexplained term will survive "as
X   is" in the new lead configuration. It may be noted that for <A5> this
X   is partly due to the asymmetry which must be present in the lead end
X   because turn #1 becomes turn #2, etc. (which is not included in the
X   calculations). However, this contribution and the other unexplained
X   terms are basically determining the expected value of <A5> = 3.0
X   unit-m.

15. The measurements on current dependence show that there is a large
    change in the allowed body harmonics <b5> and <b9> between 660 A and
    5000 A. However, there is a practically no change in the end harmonics.

16. d(b1) and sig(b1) values are inter-changed.

17. All "-"'s in d(bn) and d(an) columns are replaced by 0.0.

Oct 12, 1993

18. Table 2(d) would include the information obtained from QRI103 and
    QRI104 quadrupoles, in addition to the useful harmonics from QRI001
    and QRI002. QRI103/4 have revised coil cross section, increased yoke
    cutout for a larger shim and spiral lead to cancel part of the
    harmonics generated by the eight leads in the lead end.

19. Body <b5> and <b9> and lead end <B5>, <B9>, <A5> and <A9> are based

on the measurements in the magnets QRI103 and QRI104. The harmonics given in this table are values with nominal shims. We have reduced the values of d(bn), etc. for allowed harmonics to reflect a better confidence in the numbers since they now come from the actual measurements. Earlier the values of allowed harmonics were based on the computed values and estimated errors in the iteration.

20. We have used all four 13 cm quads built and tested so far to re-examine our previous estimates for the non-allowed harmonics. Earlier they were simply taken from the measurements in six 8 cm quads). The old values are changed if they were off by more than a factor of two. The same criterion is applied for the harmonics in the ends. We did not change those numbers which are/were very small, as those numbers could be within the errors involved in this procedure (limited statistics, etc.).

21. The <b7> measured was about -0.3 in QRI103 and QRI104.
    We are reducing it to -0.1 with an uncertainty of 0.05 because of the following reasons:
    (a) In the present design a 4 mil asymmetry in the midplane at 0 and 90 degree removes most of the <b3> but creates about -0.3 unit of <b7>.
    (b) In the Q2 and Q3 magnets and all but six Q1 magnets, the midplane asymmetry is reduced to 3 mil and the rest of the <b3> will be removed by the tuning shims which has an opposite sign for the induced <b7>. The result of this combination should be reducing <b7> to <0.1 unit.

22. Note that in tracking studies the <b7> in 6 Q1 would be -0.3 unit; These six magnets may be placed in the interaction regions where BETA* is large.

11/3/93

X 22. Based on the warm measurements in QRI105-108 and on including
X the warm measurements in QRI103 and QRI104, it appears that
X the average b5 is 0.3 unit more than what was expected only
X on the basis of QRI103 and QRI104. Also in reducing b7 from
X -0.3 unit to < |-0.1| the average midplane gets reduced by
X 0.5 mil which increase b5 by about 1/4 unit. These two together
mean that the best guess for <b5> should be increased by 1/2 unit.

X 23. As a result of the items discussed above, we now change <b5>
X from 1 unit to 1.5 unit. The target was -0.6 unit in the body.
X It is possible to reduce <b5> to a lower value by changing
X the midplane gap and/or pole shim if there is a request from the
X accelerator physicists and the solution is acceptable to management.
X The request can be treated differently for (a) rest of the Q1 magnets
X (18 or less) and (b) Q2 and Q3 magnets.

11/16/93

24. The cross section is modified so that the expected b5 in the body of the 13 cm quad at 5 kA is -1.2 starting from the Q1 magnet QRI111, to be assembled in December 1993 and continuing to rest of the program, including Q2 and Q3 magnets.

25. In addition, the cross section for the Q2 and Q3 magnet is being modified to make expected b9 in the body of the magnet to be zero.

    NOTE THAT THE EXPECTED b9 IN THE Q1 MAGNETS BUILT FROM QRI111 ONWARDS IS 0.45 UNIT AND BEFORE QRI111 IS 0.6 UNIT AT 5 KA.

    THE ABOVE TABLE LIST THE EXPECTED <b9> only IN Q2 & Q3 MAGNETS.

9/9/94

26. The tabble is revised for all QRI (Q1) magnets. However, note that only 3 of them are fully constructed (with spiral lead) and tested (cold measurements). The rest 23 are storage unit which do not have spiral leads and are only partially tested (warm only). There are three cross sections in these magnets. QRI103-110 have one cross section and would have about +1.0 unit of b5 with nominal shim at 5 kA. b9, in this cross section, would be about 0.6 unit. b7 with nominal symmetric shim would be about 0.3 unit.

    The second (third) cross section is used for QRI120 and QRI121 which gives the design b5 value of -1.2 unit with nominal shim and b9 about 0.2 unit. b7 with nominal asymmetric shim would be about -0.15 unit. This also uses Furukawa cable with a thickness reduced by about 0.3 mil. This is absorbed by increased midplane and pole shims. The cross section for Q3 (QRJ) and Q2 (QRK) magnets is basically same, except that pole and midplane shims are chosen to bring nominal b9 close to zero with nominal asymmetric tuning shims.

    For rest of the magnets, the cross section would give b5, b7 and b9 a nominal respective value of -1.2, -0.15, 0.4. However, in reality a small drift was observed during production, which was partially fixed by changing pole shims for last three magnets. A similar adjustement was also done in QRI120 and QRI121.

27. The above table is generated for "Golden Eight Magnets" to be used in BETA*=1 interaction region. In reality number is much greater than eight. Moreover, the magnets QRI120 and QRI121 also fall in that "Golden" selection.

28. The <bn> and dbn for non-allowed harmonics are interchanged to conform with the convention used in dipoles. Now expected <bn> for non-allowed harmonics is zero and dbn is non zero.

GOLDEN QRI (Q1) Table 2I(e) EXPECTED_QRI.TABLE2I_E