Fermilab

$\bar{p}$ Note #427

# SOURCES OF ACCUMULATOR COUPLING

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The strength of the coupling resonance $\nu_z-\nu_x = 2$ is determined by the value of the complex quantity

$$C = (2\pi B\rho)^{-1}\oint ds\ \sqrt{(\beta_x\beta_z)}\ \{B'+B_s[(\alpha_x-i)/\beta_x-(\alpha_z+i)/\beta_z]\}\ \exp i(\mu_z-\mu_x-\Delta\theta) \quad 1.1$$

where $B'$=skew quad gradient
$B_s$=longitudinal field
$\mu$=phase advance
$\alpha,\beta$=CSL parameters
$\Delta=\nu_{z0}-\nu_{x0}-2$
$\theta=s/R$.

$2|C|$ is equal to the minimum approach of the two fractional tunes. We can use this to estimate the contribution of various known errors to C. The observed value of $2|C|$ on the injection orbit is about $1.4\times10^{-2}$. It has been demonstrated that 30% of this is due to the extraction Lambertson magnet.

1. Currents which link the beam. The leads of each large dipole and of every quadrupole are such that the magnet current links the beam, giving rise to $B_s$. The quad currents alternate with the gradients and tend to cancel out. There is, however, a correlation between the sign of $\alpha$ and the quad polarity. On the other hand, the sign of $\alpha$ tends to change in the quads. Any real study of this contribution would be very detailed. The large dipole currents, which are about five times larger, can be easily estimated. Each current gives rise to $\int B ds=\mu_0 I = 1.5\times10^{-3}$Tm. ; $B\rho$=30Tm. Then each large dipole contributes about $8\times10^{-6}$ to C. Even if all dipoles were in the proper phase, this would still be a negligible contribution to C.

2. Quadrupole tilts. The iron bodies of the quadrupoles were levelled to a precision of about 0.1 mrad, utilizing levelling notches stamped into each lamination. The tolerance on the parallelity of these notches to the mating surfaces was never relaxed during production of the laminations. Alternation of the laminations during stacking of the cores should further reduce the effect of errors. The parallelity of the poles to the mating surface was held to a similar precision (<.001"). A quadrupole of strength B', length L, and tilt angle $\zeta$ will contribute an amount

$$C_1 = \sqrt{(\beta_z\beta_x)}\, B' L\, \zeta/2\pi B\rho. \quad 1.2$$

If the tilt angles are uncorrelated, the expectation value of the rms of the distribution of C will be

$$\sigma_C = \sqrt{N}\, [\sqrt{(\beta_z\beta_x)}\, B' L]_{mean}\, \sigma_\zeta/2\pi B\rho \quad 1.3$$

Typically, $B'L$=10T, $\sqrt{\beta_z\beta_x}$=15m, so $\sigma_C = 7\times10^{-4}$. The observed value is $10\sigma_C$.

A further check on tilts can be made by looking at the vertical dispersion, although the main contribution will be from the large quadrupoles where the horizontal dispersion is large. Let y be the difference in vertical orbit position for two orbits differing in momentum by $\delta=\Delta P/P$. Then

$$[y/\delta\sqrt{\beta_z}]_{rms} = (B' L\, \sqrt{S}/2\pi B\rho \sin \pi\nu_z)\sigma_\zeta \quad 1.4$$

where $$S = [1/2]\, \Sigma\, \beta_z\eta_x^2 \quad 1.5$$

If we use the levelling precision for $\sigma_\zeta$, we find an rms value of y, for $\delta$=.01, to be about 0.1 mm. If we use the value implied by the tune splitting, we find the rms of y to be about 1.5mm.,probably closer to reality.This should be measured again to see how closely the two measurements agree.

3. Dipole twists. Since the ends of each dipole are parallel to each other, there is a quadrupole of integrated strength $\theta B_0$ at each end of the magnet ($\theta$ is the half angle of the bend). If the magnet is twisted by an angle $2\xi$, the skew quad strength is $\xi\theta B_0$. There are 60 dipole ends of 2.5°(12), 5°(12), and 7.5°(18). The worst magnets are the early large dipoles, which had twists of $\xi$ = 2.5 mrad. The contribution to C from each LD end is about $5\times10^{-5}$. Even if all ends miraculously contributed in phase, and were equally badly twisted, they could only contibute about 40% of the coupling. Survey data exists for tilts and twists of the dipoles. The actual contribution to C could be (somewhat laboriously) calculated.

4.Skew Sextupoles. It was observed that after the feet were welded on the large quadrupoles, some undesireable skew moments were measured, and in particular skew sextupole field in the quantity of $R = 2\text{-}6 \times 10^{-4}$ of the quadrupole field at the coil radius r (=3"). This gives rise to a skew quadrupole which is dependent upon horizontal position. If the position is due to dispersion, then

$$B'_{sext} = 2\eta_x \, \delta \, B'_{quad} \, R/r \qquad 1.6$$

or an equivalent quad rotation of $\zeta = 2\eta_x \, \delta \, R/r$. For $\eta_x$=9m, $\delta$=.01, $R$=$4\times10^{-4}$ the angle is about 1mrad, or about ten times worse than the survey error. If this is a principal source of coupling, then the coupling will be strongly dependent on momentum, or radius. This should be measured by turning off the skew quad corrections and measuring the minimum approach of the fractional tunes at several momenta. Correction of this source will require a different strategy than quad sources.

5.Post Facto estimate of correction strength. The coupling at the injection orbit was corrected by application of about 35 Amps in each of two skew quads with the Lambertson off. The quads have an effective length of 26.6", and a strength of 0.5kg/in at 535 Amps. At nominal values of $\beta$ (15m), the quads should provide a correction $2|C| = 1.6\times10^{-2}$, in reasonable agreement with the minimum fractional tune approach measured.

6.Preliminary conclusions. Since the coupling is small in the debuncher, and it has few large quads, the main candidate for the coupling, beyond the Lambertson, is the large quad. We should compare the prediction of quad tilts from the vertical dispersion with that from coupling, and measure the dependence of coupling on momentum to get the contribution of the skew sextupole in the large quad.

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# SUMMARY OF SURVEY DATA FOR ACCUMULATOR TRIM DIPOLES†

| VAX NAME | LOCATED BETWEEN | NEAREST QUAD | SERIAL NUMBER | DISTANCE TO NEAREST MAGNET* | | |
|---|---|---|---|---|---|---|
| A:V102 | A1Q2-A1Q3 | A1Q2 | NDA016 | 8 7/16" | to | NSA037 |
| A:V104 | A1Q4-A1Q5 | A1Q5 | NDA020 | 18 5/16" | to | A1Q5 |
| A:H105 | A1Q5-A1Q6 | A1Q6 | NDA009 | 17 5/8" | to | A1Q6 |
| A:V106 | A1Q6-A1Q7 | A1Q7 | NDA006 | 17 3/16" | to | A1Q7 |
| A:V109 | A1Q9-A1B9 | A1Q9 | NDA012 | 11 9/16" | to | A1Q9 |
| A:V209 | A2B9-A2Q9 | A2Q9 | NDA013 | 12 3/16" | to | A2Q9 |
| A:V206 | A2Q7-A2Q6 | A2Q7 | NDA008 | 18 3/4" | to | A2Q7 |
| A:H205A | A2Q6-A2Q5 | A2Q6 | NDA010 | 17 13/16" | to | A2Q6 |
| A:V204 | A2Q5-A2Q4 | A2Q5 | NDA003 | 18 1/4" | to | A2Q5 |
| A:V202 | A2Q3-A2Q2 | A2Q2 | NDA030 | 8 3/4" | to | NSA085 |
| A:V302 | A3Q2-A3Q3 | A3Q2 | NDA027 | 6 15/16" | to | NSA095 |
| A:V304 | A3Q4-A3Q5 | A3Q5 | NDA019 | 18 3/16" | to | A3Q5 |
| A:H305 | A3Q5-A3Q6 | A3Q6 | NDA021 | 17 5/16" | to | A3Q6 |
| A:V306 | A3Q6-A3Q7 | A3Q7 | NDA001 | 18 1/8" | to | A3Q7 |
| A:V309 | A3Q9-A3B9 | A3Q9 | NDA029 | 12 1/16" | to | A3Q9 |
| A:V409 | A4B9-A4Q9 | A4Q9 | NDA011 | 12 1/8" | to | A4Q9 |
| A:V406 | A4Q7-A4Q6 | A4Q7 | NDA032 | 18 3/16" | to | A4Q7 |
| A:H405 | A4Q6-A4Q5 | A4Q6 | NDA018 | 18 3/8" | to | A4Q6 |
| A:V404 | A4Q5-A4Q4 | A4Q5 | NDB017 | 20 5/32" | to | A4Q5 |
| A:V402 | A4Q3-A4Q2 | A4Q2 | NDA031 | 15 13/16" | to | A4Q2 |
| A:V502 | A5Q2-A5Q3 | A5Q2 | NDA014 | 14 9/32" | to | A5Q2 |
| A:V504 | A5Q4-A5Q5 | A5Q5 | NDB038 | 19 15/16" | to | A5Q5 |
| A:H505 | A5Q5-A5Q6 | A5Q6 | NDA024 | 18 1/4" | to | A5Q6 |
| A:V506 | A5Q6-A5Q7 | A5Q7 | NDA004 | 17 3/4" | to | A5Q7 |
| A:V509 | A5Q9-A5B9 | A5Q9 | NDA025 | 11 3/4" | to | A5Q9 |
| A:V609 | A6B9-A6Q9 | A6Q9 | NDA005 | 12 5/8" | to | A6Q9 |
| A:V606 | A6Q7-A6Q6 | A6Q7 | NDA026 | 18 3/8" | to | A6Q7 |
| A:H605 | A6Q6-A6Q5 | A6Q6 | NDA022 | 18 1/8" | to | A6Q6 |
| A:V604 | A6Q5-A6Q4 | A6Q5 | NDA007 | 18 3/8" | to | A6Q5 |
| A:V602 | A6Q3-A6Q2 | A6Q2 | NDA028 | 7 15/16" | to | NSA092 |

† Data taken by O'Boyle + Howat May 22-23, 1985, except A:V504 + A:V404 which were done by Lennox 7-11-85.

* Measured from dipole center to steel of nearest magnet.