MEASUREMENT OF RIPPLE IN THE ACCUMULATOR BEND BUS SUPPLY

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I. Introduction

E760 uses the longitudinal Schottky spectrum of the circulating beam in the Accumulator to measure the momentum spectrum of the beam with the assumption that $\Delta p/p = \frac{1}{\eta} * \Delta f/f$. However, the presence of low frequency ripple in the bus current could modulate this spectrum so that the above relation is not true. Therefore an attempt was made to measure this ripple to see if it had a significant affect on the frequency spectrum.

II. Calculation

The longitudinal Schottky current at the pickup P is given by

$$I^P(t) = q \sum_{j=1}^{N} \sum_{m=-\infty}^{+\infty} \omega_j \cdot \delta(\theta_j(t) - \theta_P - 2m\pi) \tag{1}$$

where

$$\omega_j = \omega_{0j} + A\omega_R cos(\omega_R t), \tag{2}$$

and

$$\theta_j(t) = \omega_{0j} t + Asin(\omega_R t) + \psi_j^0. \tag{3}$$

The sum j is over the N beam particles, A is the amplitude of the ripple (in radians), ω_R is the ripple frequency, and θ_P is the azimuthal location of the pickup. Using the Fourier series representation of the periodic δ function, this becomes

$$I^P(t) = q \sum_{j=1}^{N} \frac{\omega_j}{2\pi} \sum_{m=-\infty}^{\infty} e^{-im(\omega_{0j} t - \theta_j^0)} \cdot e^{-imAsin(\omega_R t)} \tag{4}$$

where

$$\theta_j^0 = \theta_P - \psi_j^0. \tag{5}$$

Using the bessel function relation

$$e^{-ixsiny} = \sum_{k=-\infty}^{\infty} J_k(x) e^{-iky}, \tag{6}$$

yields

$$I_P(t) = \frac{q}{2\pi} \sum_{j=1}^{\infty} \omega_{0j} e^{-im(\omega_{0j}t - \theta_j^0)} \sum_{k=-\infty}^{\infty} J_k(mA) e^{-ik\omega_R t} \tag{7}$$

where I have used $\omega_{0j} \simeq \omega_j$.

The autocorrelation function is

$$C(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{+T} < I^P(t) I^P(t+\tau) > dt \tag{8}$$

where the average is over θ. After averaging, analyzing δ functions, and taking the limit, this becomes

$$C(\tau) = \frac{q^2}{(2\pi)^2} \sum_{jkm} \omega_{0j}^2 J_k^2(mA) e^{im\omega_{0j}\tau} e^{ik\omega_R \tau}. \tag{9}$$

The power spectrum is then

$$P(\Omega) = \int_{-\infty}^{+\infty} d\tau \frac{q^2}{(2\pi)^2} \sum_{jkm} \omega_{0j}^2 J_k^2(mA) e^{i(m\omega_{0j} + k\omega_R - \Omega)t}. \tag{10}$$

Let

$$\sum_j \longrightarrow N \int d\omega_0 \Psi(\omega_0) \quad \text{where} \quad \int_{-\infty}^{+\infty} d\omega_o \Psi(\omega_o) = 1 \tag{11}$$

so that

$$P(\Omega) = \sum_{km} \frac{Nq^2}{2\pi m^3} J_k^2(mA)(\Omega - k\omega_R)^2 \Psi(\frac{\Omega - k\omega_R}{m}). \tag{12}$$

For the mth harmonic this is

$$P_m(\Omega) = \frac{Nq^2}{2\pi m^3} J_0^2(mA)\Omega^2 \Psi(\frac{\Omega}{m}) \; +$$

$$\frac{Nq^2}{2\pi m^3} \sum_{k=1}^{\infty} J_k^2(mA)[(\Omega - k\omega_R)^2 \Psi(\frac{\Omega - k\omega_R}{m}) + (\Omega + k\omega_R)^2 \Psi(\frac{\Omega + k\omega_R}{m})]. \tag{13}$$

A is given by

$$A = \frac{\omega_0}{\omega_R} \frac{\Delta B}{B} \frac{1}{\gamma_T^2} \tag{14}$$

where B is the magnetic field and ΔB is the magnitude of the magnetic field ripple.

III. Measurement

In order to measure the ripple in the Accumulator bend field a wire coil was placed inside the dipole magnet which also contains the NMR probe. The frequency power spectrum was then measured at several different magnetic field values. A typical frequency spectrum is shown in Fig. 1. The voltage generated across the coil is

$$V = -\frac{dB}{dt} \pi R^2 N \tag{15}$$

where N is the number of turns (100) and R is the radius (.05m). If we take

$$B = B_0 + \Delta B cos(\omega_R t) \tag{16}$$

then the RMS power into 50Ω (in watts) is

$$P_{rms} = .0987(\Delta B \omega_R R^2 N)^2, \tag{17}$$

and the magnitude of the magnetic field ripple can be extracted from plots such as Fig. 1. The signal was carried from the tunnel to the AP30 service building on a twin-axial cable and the measurement was made differentially on an HP 3562A Dynamic Signal Analyzer.

Table 1 summarizes the data taken. The noise (0 field) measurements are well below the signals measured with the bend bus on, although there is no clear relationship between magnetic field strength and ripple size. The source of this ripple is not clear and it is not necessarily coming from the magnetic field – since the coil itself was not well shielded. Therefore, these measurements should be taken as an upper limit on ripple size. In addition, a stainless steel beampipe will partially filter out low frequency magnetic oscillations, therefore the measurements presented here must be considered upper limits for this reason also.

The magnitude of $\Delta B/B$ for the different measured cases is tabulated in Table 2. The calculation uses eq. 17. Table 3 shows the calculated affect of ripple on the width of the beam using eq. 13. The 3 magnetic field cases are 1.67, 1.12, and 0.77 Tesla. For each magnetic field case 4 different unperturbed beam widths (sigma) are considered – 140, 160, 180, and 200 Hz @ harmonic 127 which were typical widths during the double scans. σ is the unperturbed beam width, σ_1 is the ripple-perturbed sigma, and σ_2 is the ripple-perturbed 2 x sigma. The last column is the percent change in the beam sigma due to the ripple. The worst case is .14% which is entirely negligible for E760's purposes.

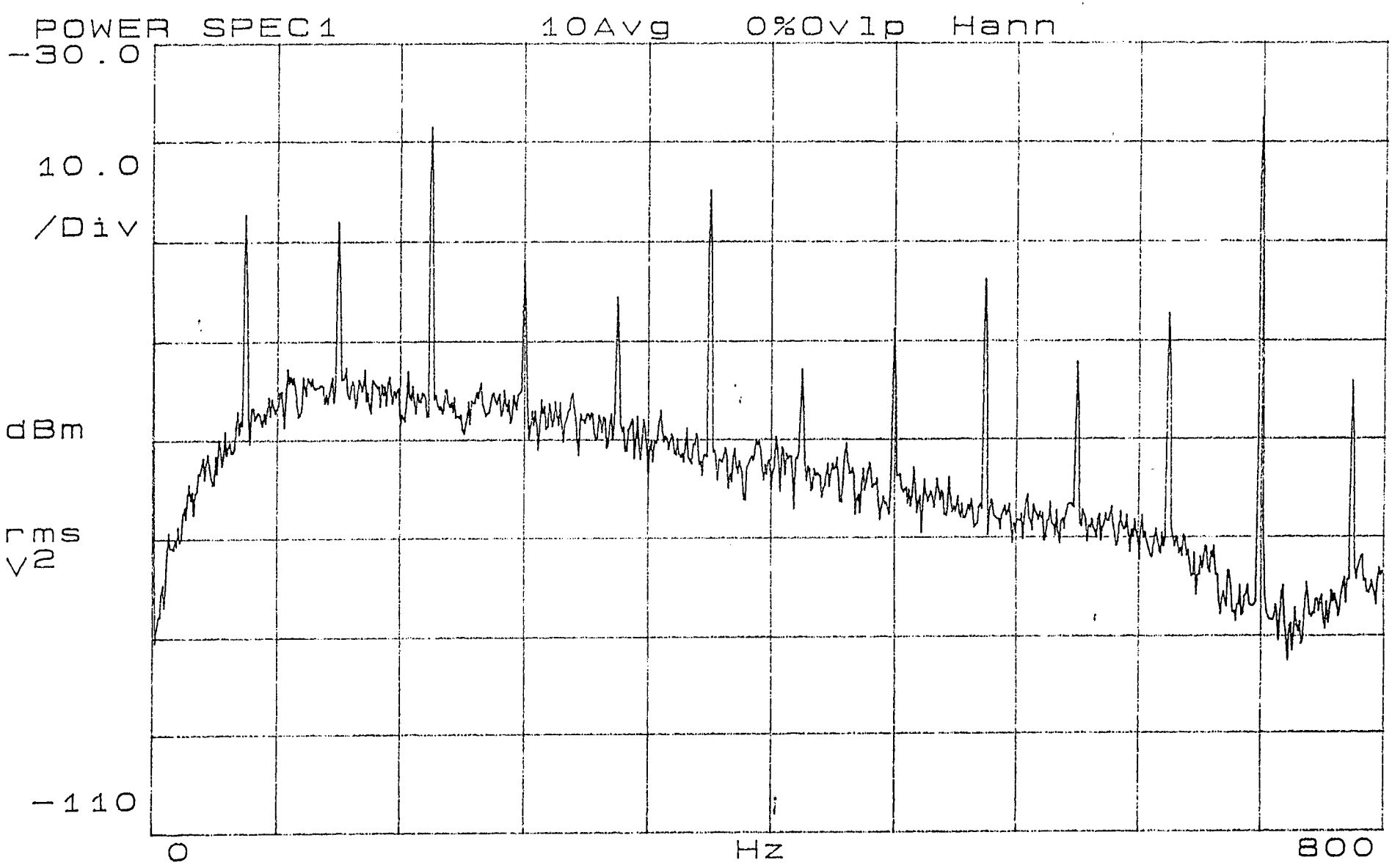

Fig 1. Frequency spectrum from Tesla coil @ A:BFIELD = 16752 gauss, A:IB = 1171 amps

freq. (Hz)	Bfield (gauss) -- A:IB (amps) 16752 -- 1171	11161 -- 745	7718 -- 513	0 -- 0
60	-47.3	-47.6	-51.8	-100.9
120	-46.0	-41.8	-47.9	-111.8
180	-38.6	-52.9	-48.4	-101.9
240	-53.6	-50.1	-55.7	-113.8
300	-53.2	-53.4	-56.0	-92.3
360	-43.9	-39.4	-36.6	-94.4
420	-60.8	-58.8	-56.7	-94.8
480	-59.0	-60.6	-61.9	-105.8
540	-52.8	-54.1	-59.7	-104.8
600	-64.1	-61.3	-62.3	-103.9
660	-59.7	-64.0	-63.1	-92.6
720	-36.1	-33.0	-32.5	-94.7

TABLE 1: measured power (dBm) for different frequency and Bfield values

From FNWS07:: USR$ROOT1: [CHURCH.ACNET]RIPPLE2.FOR

averaged from measurements

B= 1.67 tesla

F= 60. hz	DB/B=0.0000023	Vpeak= 1.147 mv	Prms=0.186E-04 mw	dBm=-47.3
F=120. hz	DB/B=0.0000013	Vpeak= 1.333 mv	Prms=0.251E-04 mw	dBm=-46.0
F=180. hz	DB/B=0.0000021	Vpeak= 3.124 mv	Prms=0.138E-03 mw	dBm=-38.6
F=240. hz	DB/B=0.0000003	Vpeak= 0.556 mv	Prms=0.437E-05 mw	dBm=-53.6
F=300. hz	DB/B=0.0000002	Vpeak= 0.582 mv	Prms=0.479E-05 mw	dBm=-53.2
F=360. hz	DB/B=0.0000006	Vpeak= 1.697 mv	Prms=0.407E-04 mw	dBm=-43.9
F=420. hz	DB/B=0.0000001	Vpeak= 0.243 mv	Prms=0.832E-06 mw	dBm=-60.8
F=480. hz	DB/B=0.0000001	Vpeak= 0.298 mv	Prms=0.126E-05 mw	dBm=-59.0
F=540. hz	DB/B=0.0000001	Vpeak= 0.609 mv	Prms=0.525E-05 mw	dBm=-52.8
F=600. hz	DB/B=0.0000000	Vpeak= 0.166 mv	Prms=0.389E-06 mw	dBm=-64.1
F=660. hz	DB/B=0.0000001	Vpeak= 0.275 mv	Prms=0.107E-05 mw	dBm=-59.7
F=720. hz	DB/B=0.0000007	Vpeak= 4.166 mv	Prms=0.245E-03 mw	dBm=-36.1

B= 1.12 tesla

F= 60. hz	DB/B=0.0000033	Vpeak= 1.109 mv	Prms=0.174E-04 mw	dBm=-47.6
F=120. hz	DB/B=0.0000033	Vpeak= 2.161 mv	Prms=0.661E-04 mw	dBm=-41.8
F=180. hz	DB/B=0.0000006	Vpeak= 0.602 mv	Prms=0.513E-05 mw	dBm=-52.9
F=240. hz	DB/B=0.0000006	Vpeak= 0.831 mv	Prms=0.977E-05 mw	dBm=-50.1
F=300. hz	DB/B=0.0000003	Vpeak= 0.569 mv	Prms=0.457E-05 mw	dBm=-53.4
F=360. hz	DB/B=0.0000014	Vpeak= 2.849 mv	Prms=0.115E-03 mw	dBm=-39.4
F=420. hz	DB/B=0.0000001	Vpeak= 0.305 mv	Prms=0.132E-05 mw	dBm=-58.8
F=480. hz	DB/B=0.0000001	Vpeak= 0.248 mv	Prms=0.871E-06 mw	dBm=-60.6
F=540. hz	DB/B=0.0000002	Vpeak= 0.524 mv	Prms=0.389E-05 mw	dBm=-54.1
F=600. hz	DB/B=0.0000001	Vpeak= 0.229 mv	Prms=0.741E-06 mw	dBm=-61.3
F=660. hz	DB/B=0.0000000	Vpeak= 0.168 mv	Prms=0.398E-06 mw	dBm=-64.0
F=720. hz	DB/B=0.0000015	Vpeak= 5.953 mv	Prms=0.501E-03 mw	dBm=-33.0

B= 0.77 tesla

F= 60. hz	DB/B=0.0000030	Vpeak= 0.684 mv	Prms=0.661E-05 mw	dBm=-51.8
F=120. hz	DB/B=0.0000023	Vpeak= 1.071 mv	Prms=0.162E-04 mw	dBm=-47.9
F=180. hz	DB/B=0.0000015	Vpeak= 1.011 mv	Prms=0.145E-04 mw	dBm=-48.4
F=240. hz	DB/B=0.0000005	Vpeak= 0.436 mv	Prms=0.269E-05 mw	dBm=-55.7
F=300. hz	DB/B=0.0000004	Vpeak= 0.421 mv	Prms=0.251E-05 mw	dBm=-56.0
F=360. hz	DB/B=0.0000029	Vpeak= 3.933 mv	Prms=0.219E-03 mw	dBm=-36.6
F=420. hz	DB/B=0.0000002	Vpeak= 0.389 mv	Prms=0.214E-05 mw	dBm=-56.7
F=480. hz	DB/B=0.0000001	Vpeak= 0.214 mv	Prms=0.646E-06 mw	dBm=-61.9
F=540. hz	DB/B=0.0000001	Vpeak= 0.275 mv	Prms=0.107E-05 mw	dBm=-59.7
F=600. hz	DB/B=0.0000001	Vpeak= 0.204 mv	Prms=0.589E-06 mw	dBm=-62.3
F=660. hz	DB/B=0.0000001	Vpeak= 0.186 mv	Prms=0.490E-06 mw	dBm=-63.1
F=720. hz	DB/B=0.0000023	Vpeak= 6.306 mv	Prms=0.562E-03 mw	dBm=-32.5

Table 2: $\frac{\Delta B}{B}$ calculated from frequency spectrum measurements

harmonic 127
max. bessel fnct 12
pts within 1 sigma 800

B=1.67 tesla Frev=629000. hz GAMMAT=5.35

SIGMA BEAM=140. hz

		σ	σ_1	σ_2	% change
60.	0.0000023	140.	139.74	280.79	0.05
120.	0.0000013	140.	139.74	280.61	0.02
180.	0.0000021	140.	139.74	280.61	0.02
240.	0.0000003	140.	139.74	280.61	0.02
300.	0.0000002	140.	139.74	280.61	0.02
360.	0.0000006	140.	139.74	280.61	0.02
420.	0.0000001	140.	139.74	280.61	0.02
480.	0.0000001	140.	139.74	280.61	0.02
540.	0.0000001	140.	139.74	280.61	0.02
600.	0.0000000	140.	139.74	280.61	0.02
660.	0.0000001	140.	139.74	280.61	0.02
720.	0.0000007	140.	139.74	280.61	0.02

SIGMA BEAM=160. hz

60.	0.0000023	160.	159.70	320.70	0.02
120.	0.0000013	160.	159.70	320.70	0.02
180.	0.0000021	160.	159.70	320.70	0.02
240.	0.0000003	160.	159.70	320.70	0.02
300.	0.0000002	160.	159.70	320.70	0.02
360.	0.0000006	160.	159.70	320.70	0.02
420.	0.0000001	160.	159.70	320.70	0.02
480.	0.0000001	160.	159.70	320.70	0.02
540.	0.0000001	160.	159.70	320.70	0.02
600.	0.0000000	160.	159.70	320.70	0.02
660.	0.0000001	160.	159.70	320.70	0.02
720.	0.0000007	160.	159.70	320.70	0.02

SIGMA BEAM=180. hz

60.	0.0000023	180.	179.66	360.79	0.02
120.	0.0000013	180.	179.66	360.79	0.02
180.	0.0000021	180.	179.66	360.79	0.02
240.	0.0000003	180.	179.66	360.79	0.02
300.	0.0000002	180.	179.66	360.79	0.02
360.	0.0000006	180.	179.66	360.79	0.02
420.	0.0000001	180.	179.66	360.79	0.02
480.	0.0000001	180.	179.66	360.79	0.02
540.	0.0000001	180.	179.66	360.79	0.02
600.	0.0000000	180.	179.66	360.79	0.02
660.	0.0000001	180.	179.66	360.79	0.02
720.	0.0000007	180.	179.66	360.79	0.02

SIGMA BEAM=200. hz

60.	0.0000023	200.	199.63	400.88	0.02
120.	0.0000013	200.	199.63	400.88	0.02
180.	0.0000021	200.	199.63	400.88	0.02
240.	0.0000003	200.	199.63	400.88	0.02
300.	0.0000002	200.	199.63	400.88	0.02
360.	0.0000006	200.	199.63	400.88	0.02
420.	0.0000001	200.	199.63	400.88	0.02
480.	0.0000001	200.	199.63	400.88	0.02

TABLE 3

480.	0.0000001	200.	199.63	400.88	0.02
540.	0.0000002	200.	199.63	400.88	0.02
600.	0.0000001	200.	199.63	400.88	0.02
660.	0.0000000	200.	199.63	400.88	0.02
720.	0.0000015	200.	199.63	400.88	0.02

B=0.77 tesla Frev=616000. hz GAMMAT=5.54

SIGMA BEAM=140. hz

60.	0.0000030	140.	139.74	280.79	0.05
120.	0.0000023	140.	139.74	280.61	0.02
180.	0.0000015	140.	139.74	280.61	0.02
240.	0.0000005	140.	139.74	280.61	0.02
300.	0.0000004	140.	139.74	280.61	0.02
360.	0.0000029	140.	139.74	280.79	0.05
420.	0.0000002	140.	139.74	280.61	0.02
480.	0.0000001	140.	139.74	280.61	0.02
540.	0.0000001	140.	139.74	280.61	0.02
600.	0.0000001	140.	139.74	280.61	0.02
660.	0.0000001	140.	139.74	280.61	0.02
720.	0.0000023	140.	139.74	280.61	0.02

SIGMA BEAM=160. hz

60.	0.0000030	160.	159.70	320.90	0.05
120.	0.0000023	160.	159.70	320.70	0.02
180.	0.0000015	160.	159.70	320.70	0.02
240.	0.0000005	160.	159.70	320.70	0.02
300.	0.0000004	160.	159.70	320.70	0.02
360.	0.0000029	160.	159.70	320.90	0.05
420.	0.0000002	160.	159.70	320.70	0.02
480.	0.0000001	160.	159.70	320.70	0.02
540.	0.0000001	160.	159.70	320.70	0.02
600.	0.0000001	160.	159.70	320.70	0.02
660.	0.0000001	160.	159.70	320.70	0.02
720.	0.0000023	160.	159.70	320.70	0.02

TABLE 3

SIGMA BEAM=180. hz

60.	0.0000030	180.	179.66	360.79	0.02
120.	0.0000023	180.	179.66	360.79	0.02
180.	0.0000015	180.	179.66	360.79	0.02
240.	0.0000005	180.	179.66	360.79	0.02
300.	0.0000004	180.	179.66	360.79	0.02
360.	0.0000029	180.	179.66	360.79	0.02
420.	0.0000002	180.	179.66	360.79	0.02
480.	0.0000001	180.	179.66	360.79	0.02
540.	0.0000001	180.	179.66	360.79	0.02
600.	0.0000001	180.	179.66	360.79	0.02
660.	0.0000001	180.	179.66	360.79	0.02
720.	0.0000023	180.	179.66	360.79	0.02

SIGMA BEAM=200. hz

60.	0.0000030	200.	199.63	400.88	0.02
120.	0.0000023	200.	199.63	400.88	0.02
180.	0.0000015	200.	199.63	400.88	0.02
240.	0.0000005	200.	199.63	400.88	0.02
300.	0.0000004	200.	199.63	400.88	0.02
360.	0.0000029	200.	199.63	400.88	0.02

420.	0.0000002	200.	199.63	400.88	0.02
480.	0.0000001	200.	199.63	400.88	0.02
540.	0.0000001	200.	199.63	400.88	0.02
600.	0.0000001	200.	199.63	400.88	0.02
660.	0.0000001	200.	199.63	400.88	0.02
720.	0.0000023	200.	199.63	400.88	0.02

TABLE 3