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Tuning Curves

S. Tepikian

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Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

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S. Tepikian, V. Mane, S. Peggs

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I. Introduction

During the beta squeeze of the RHIC lattice, some of the quadrupole strengths will need to be adjusted. Since, the power supplies are in a complex configuration involving shunt supplies on a main bus [Figure 1], changing one of these supplies can affect many quadrupoles. A preliminary version of the 'ramp' code is presented in order to manage the power supply adjustments when a given choice of quadrupole strengths are to be changed.

In the standard operation of RHIC, the beta function at the crossing point, denoted as β^*, will be adjustable from 1 m to 10 m. The operating tunes are to be nominally set at $\nu_x = 28.19$ and $\nu_y = 29.18$.

The power supply currents were calculated for standard range of β^* and at the six different operating tunes shown in Figure 2. These results also give ranges needed for the power supplies. The following sections describe in detail the calculations mentioned above.

II. Quadrupole Strengths

The insertion consists of the following tunable components:

1. Six quadrupoles with a 13 cm coil internal diameter (ID), three on each side of the crossing point (denoted as the triplets).
2. Six trim quadrupoles, three on either side of the crossing point.
3. Twelve quadrupoles with an 8 cm coil ID, six are on either side of the crossing point.

Of these 24 quadrupoles, 20 are tuned anti-symmetrically. The power supply arrangement allows breaking the anti-symmetry of the triplets and the trim quadrupoles if additional corrections are needed.

The RHIC lattice is modeled in MAD version 8.17 language [1], where optimization of the insertion is performed. The insertion is optimized to set the particular β^*, to match the insertion to the arcs and to minimize the β_{max} [2]. Matching is necessary so that each insertion can be tuned independently with negligible perturbations to the rest of the machine. During the optimization process the following 11 parameters are varied:

1. the triplet quadrupoles Q1, Q2 and Q3
2. the trim quadrupole Q6T,
3. the 8cm quadrupoles, QFA and QDA
4. the arc quadrupoles QF and QD
5. and three more parameters are varied as given in Table 1.

There is an additional degree of freedom in the Q4, Q4T, Q5, Q5T, Q6 and Q6T quadrupoles. The quadrupoles Q4, Q5 and Q6 are on the same bus, denoted as Q4(56), whose current is adjustable with the shunt supplies. Increasing or decreasing this current can be corrected by readjusting the trim quadrupoles Q4T, Q5T and Q6T which have their own separate power supplies. Thus, an additional requirement is introduced to take care of this freedom. Carefully choosing this requirement, given in Table 1, can minimize the power supply currents ranges.

Table 1: The Three Variable Parameters

Range	Requirement	Three variable parameters
$\beta^* < 1.5m$	$Q4\,(56) = \text{Constant}$	$Q4T \quad Q5T \quad Q7$
$1.5m \le \beta^* < 9m$	$Q4T = -Q5T$	$Q4(56) \quad Q4T \quad Q7$
$9m \le \beta^*$	$Q7 = Q4\,(56)$	$Q4T \quad Q5T \quad Q7$

The range shown in Table 1 is optimum for the tunes $\nu_x = 28.19$ and $\nu_y = 29.18$. The optimum range may differ for the other tunes. Figures 3-1, 3-2 and 3-3 give the quadrupole gradients as a function of β^*, at the six operating tunes [Figure 2], and at the top energy of RHIC ($B\rho = 839.5$ T - m). The different requirements in Table 1 are necessary to reduce the overall power supply currents and lead capacity.

III. Power Supply Currents

A set of three C programs 'itf', 'strcur' and 'ips' are written to convert the magnet strengths to power supply currents. These programs are part of the 'ramp' application code. Therefore given any wiring configuration between the magnets and the power supplies, the program calculates the power supply currents.

The program 'itf' (inverse transfer function) reads a transfer function of quadrupole gradients B' vs. currents, I, from the transfer function table and writes the inverse transfer function to a binary SDS file [3].

The program 'strcur' (strength current) reads the magnet strengths from the 'beta_squeeze' database table, and converts it to gradients. The transfer function table names for each strength are read from a conversion table. In this example three transfer functions are used: 8 cm, 13 cm and the trim quadrupoles [4]. A rational interpolation of the transfer function is done to obtain the magnet currents from the gradients [5]. Figures 4-1 and 4-2 give the quadrupole currents at the horizontal and vertical tunes (28.19,29.18).

As shown in Figure 1, a magnet can be connected to many power supplies and vice versa. For each magnet, the program 'ips' reads the power supplies affecting it, the polarity and the power supply limits. These are obtained from a relational database which is described in [6]. A system of linear equations is obtained, where the power supply currents are the unknowns. Eq (1) gives the matrix for this system of equation, for the IR wiring configuration in Figure 1. The linear simplex method of optimization is used to solve this system of equations [7]. The power supply limits are given as additional constraints. One advantage to using this method is that two (or more) rows or columns can be equal in this matrix. The matrix does not has to be square and the number of power supplies can be more than the number of magnets.

$$
\begin{bmatrix} IQ1 \\ IQ2 \\ IQ3 \\ IQT4 \\ IQT5 \\ IQT6 \\ IQ7 \\ IQFA \\ IQDA \\ IQF \\ IQD \\ IQ4 \\ IQ5 \\ IQ6 \end{bmatrix}
=
\begin{bmatrix}
1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix} IPS1 \\ IPS2 \\ IPS3 \\ IPS7 \\ IPSF \\ IPS456 \\ IPSQT4 \\ IPSQT5 \\ IPSQT6 \\ IPSFA \\ IPSDA \\ IPSD \end{bmatrix}
\qquad (1)
$$

IQ1, IQ2.. . IQ6 are the currents in the magnets Q1, Q2.. . Q6, and IPS1, IPS2. ..I PSD are the currents in the power supplies PS1, PS2.. ..PSD.

Figure 5 gives an example of an output from 'ips' giving power supply matrix and currents for the above mentioned wiring configuration and magnet currents.

All of the above mentioned tables are currently in the database 'rhic_2'. This is a temporary database used to test and produce working codes, until the appropriate databases and table formats are decided by the database team members.

For the quadrupole gradients given in Figure 3-1 thru 3-3, the power supply currents are given in Figure 6-1 thru 6-4. Some of the power supply limits were modified to encompass the required power supply ranges. Table 2 lists the hardware power supply limits (including modifications), and the requested power supply ranges [8].

Table 2: Power Supply Requirements (β* 1-10 m)

PS Name	Hardware Limits		Required Limits		% Required/ Hardware
	Min	Max	Min	Max	
PS1	-300*	300*	50	154	51
PS2	-150	150	-35	103	69
PS3	-300*	0*	-257	-123	85
PSQT4	-150	150	-85	113	75
PSQT5	-150	150	-85	81	57
PSQT6	-150	150	-44	71	47
PS(45)6	0	450	0	413	92
PS7	0	750*	161	563	75
PSFA	-150	150	84	97	65
PSDA	-450	450	-300	180	67
PSF	0	5500	4494	4633	84
PSD	0	5500	4648	4787	87
H/V**	0	450*	110	199	44

* Modified Limit

**Offset between PSF and PSD

IV. Conclusions

The quadrupole strengths for beta squeeze have been adjusted to reduce the required power supply currents.

The limits of the power supplies PS1, PS3, PS7 and H/V offset have been modified, so that the required limits are well within the hardware limits.

The 'ramp' application code calculates power supply currents, for any given wiring configuration between the magnets and the power supplies.

The 'ramp' code calculates power supply currents, for a given choice of quadrupole gradients.

V. References

[1] A. Grote, F. C. Iselin, CERN/SL/90-13 (AP), 1990.

[2] S. Tepikian, M. Harrison, AD/RHIC/AP-103, 1992.

[3] ISTK collaboration.

[4] D. Trbojevic, RHIC/AP/ Note to be published.

[5] Numerical Recipes in C, p111, W. H. Press, S. A. Teukolsky, W. T. Vetterling, B. P. Flannery.

[6] T. Satogata, RHIC/AP Note, to be published.

[7] Numerical Recipes in C, p430

[8] M. Harrison, B. Lambiase, Private Communication.

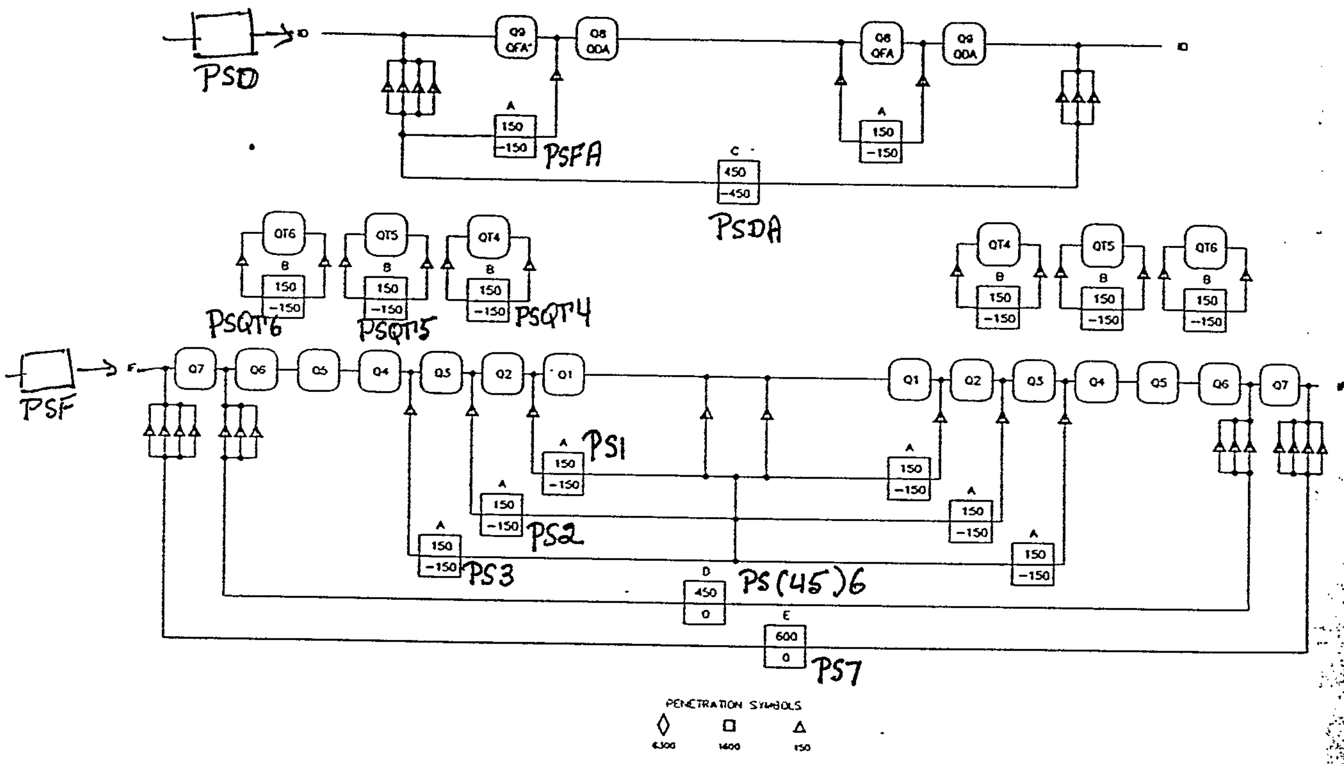


Fig. 1 Insertion quads at 2, 6, 8 and 12 o'clock.

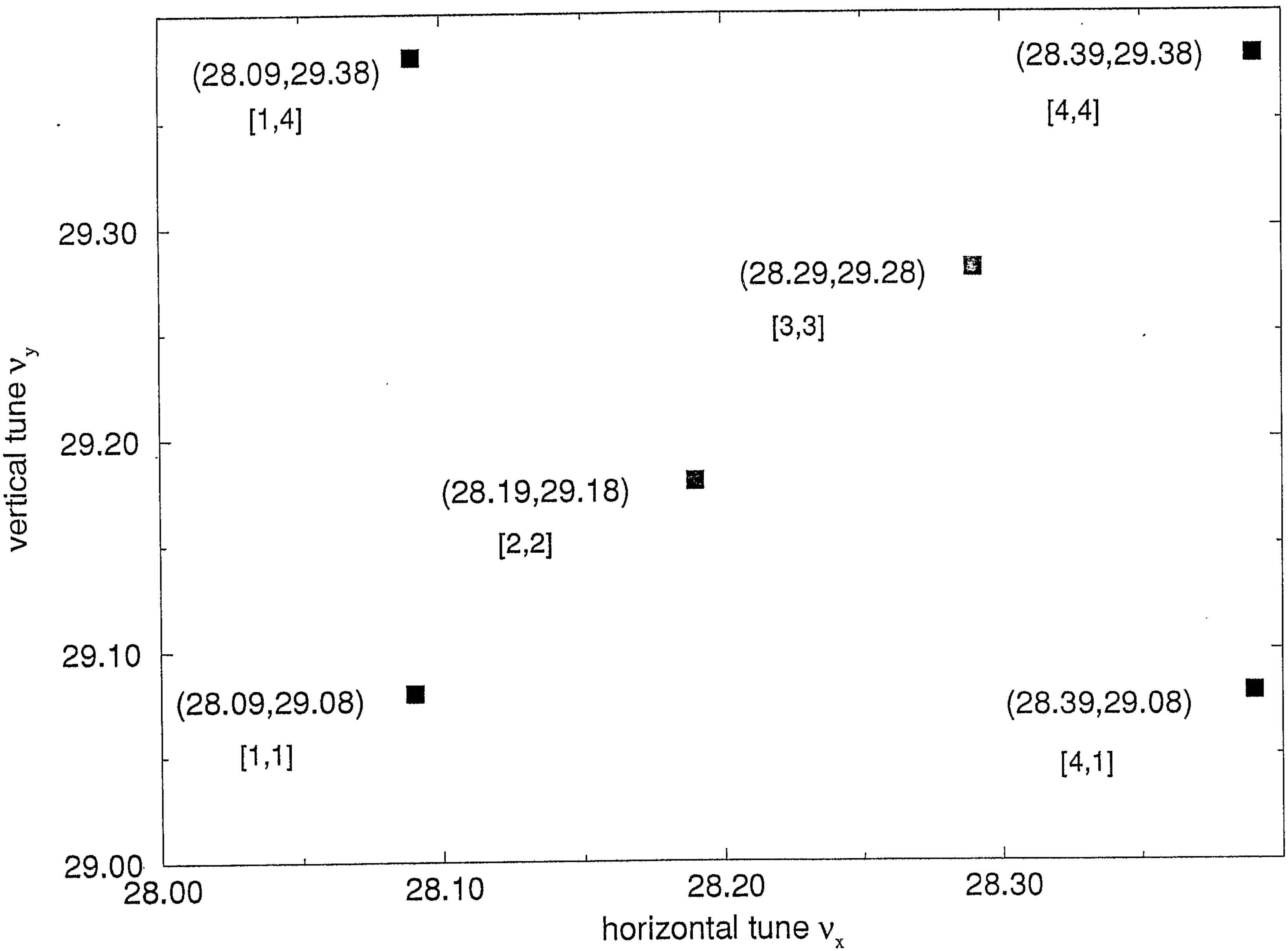
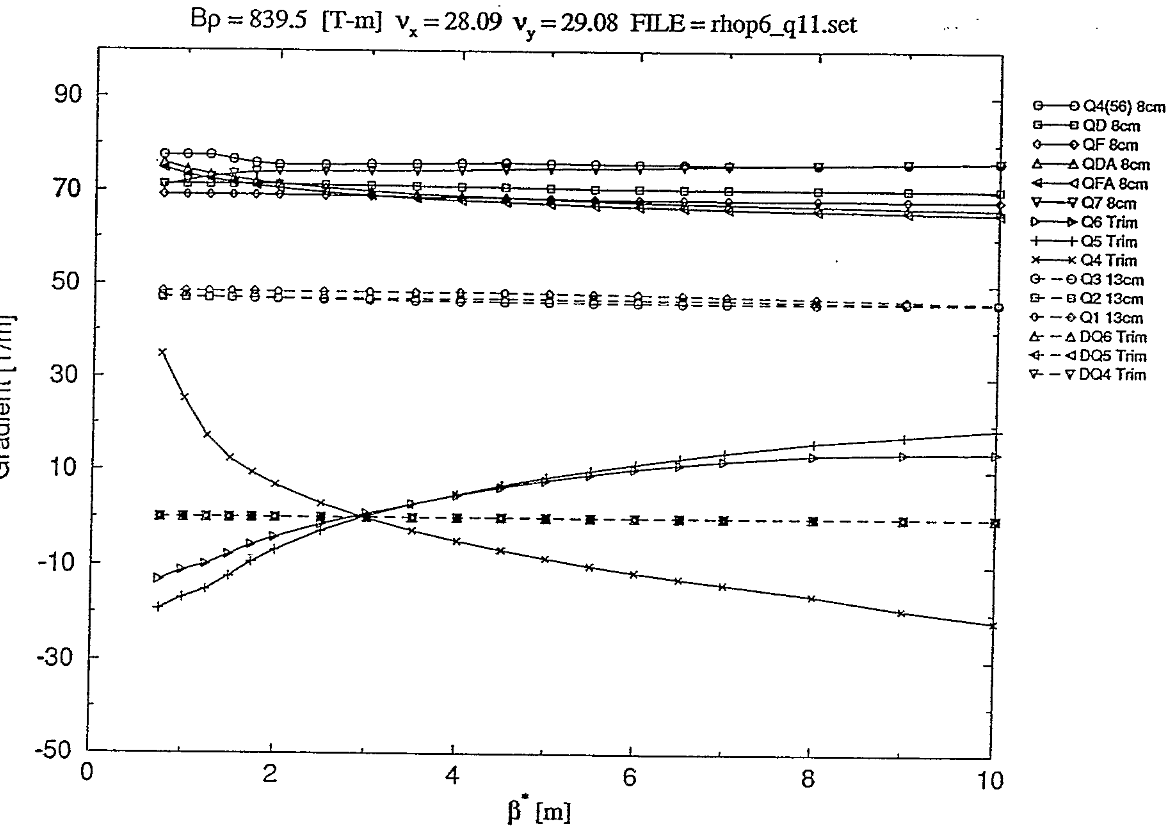


Fig 2. Tune Plot [The numbers in parenthesis denote fractional part of tune]



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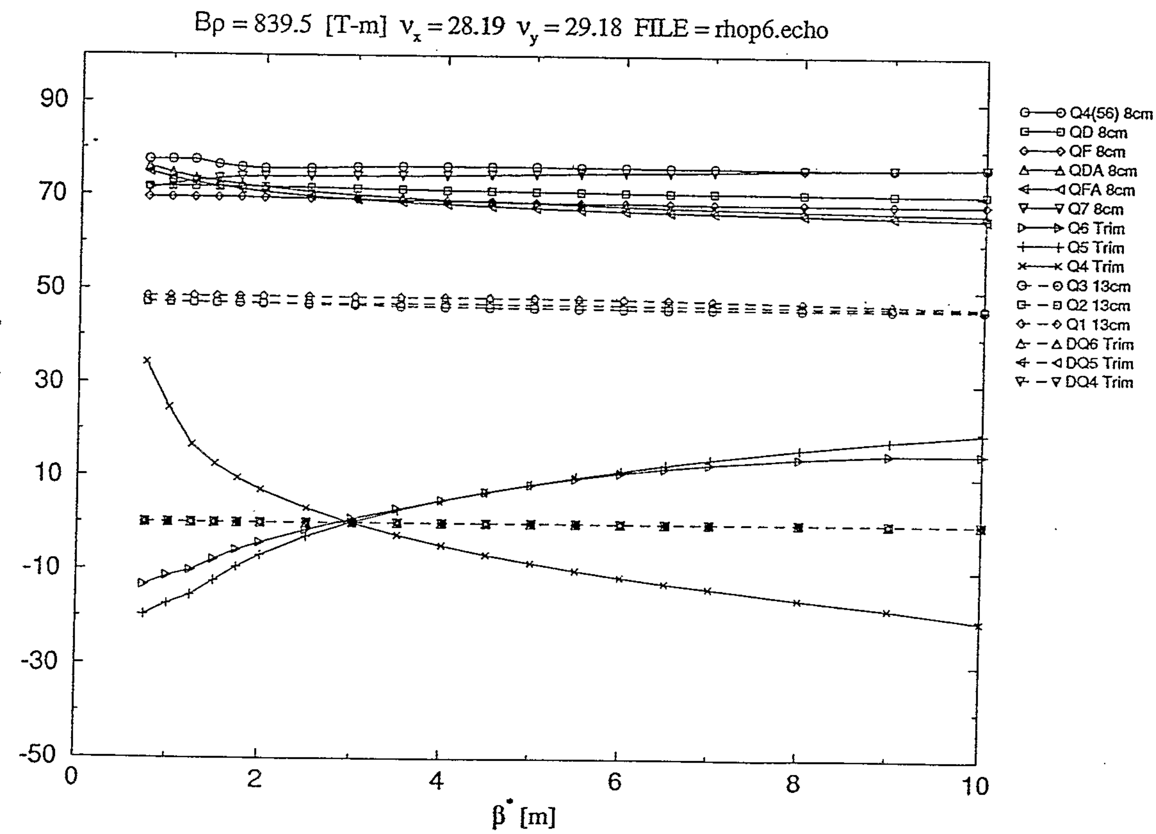
[a]



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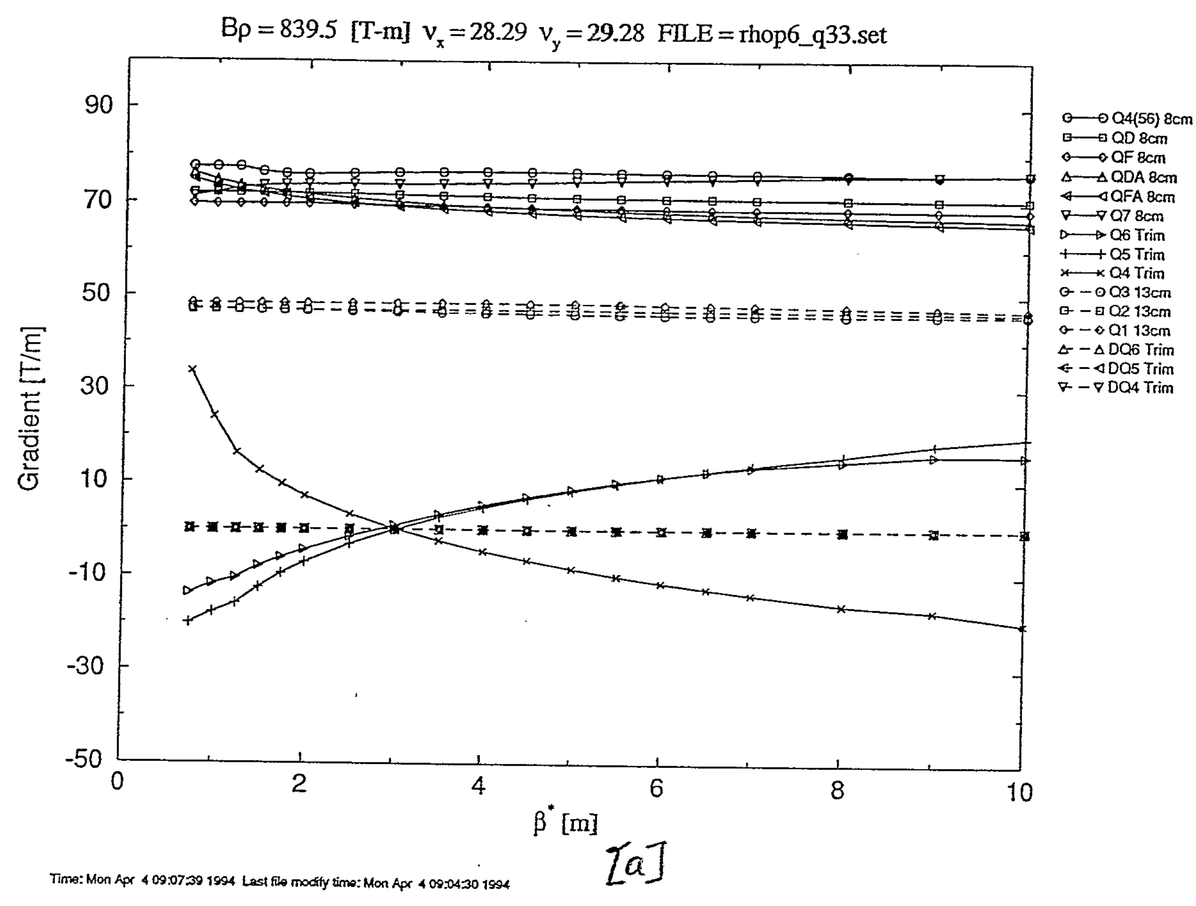
[b]

Fig. 3-1: Insertion Quadrupole Gradients
[a] tune [1,1] [b] tune [2,2]

(28.39,29.38)

(28.09,29.38)



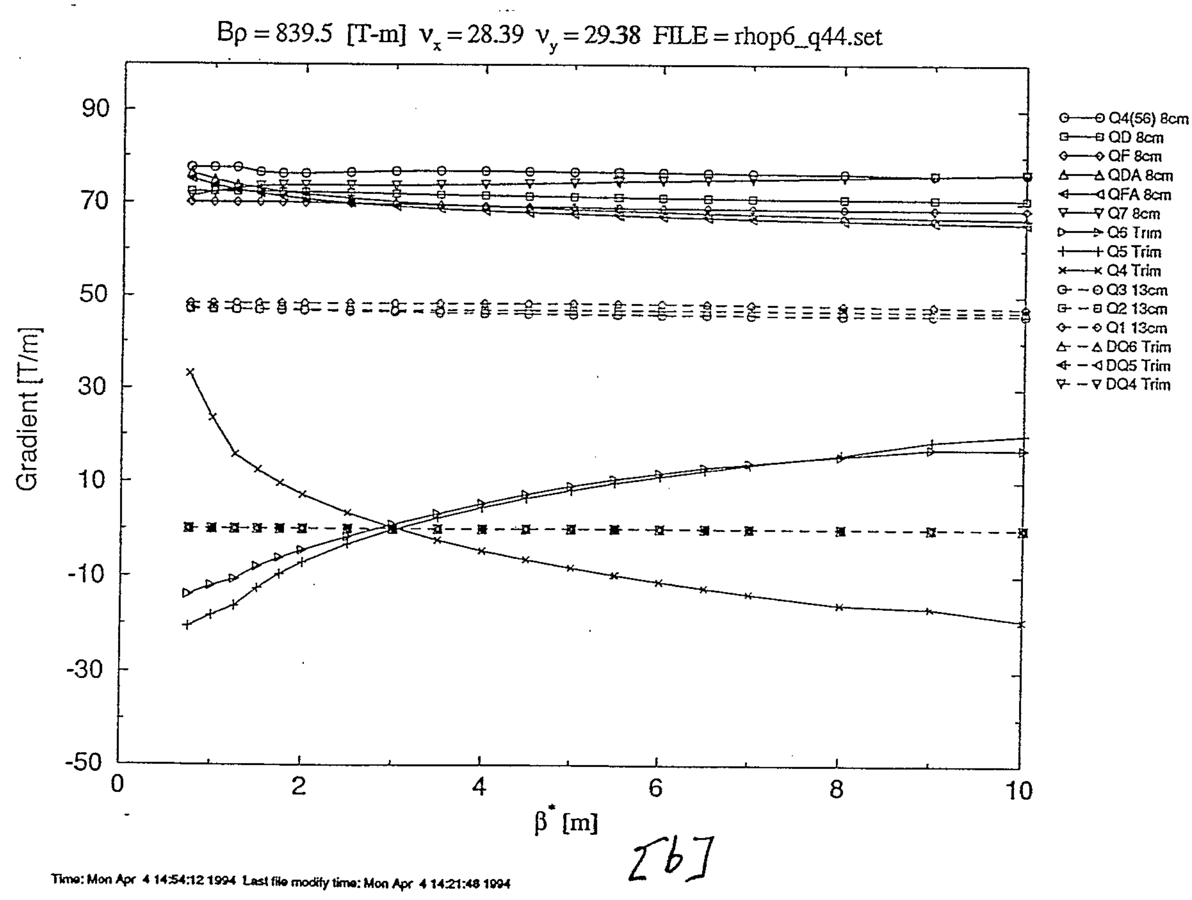
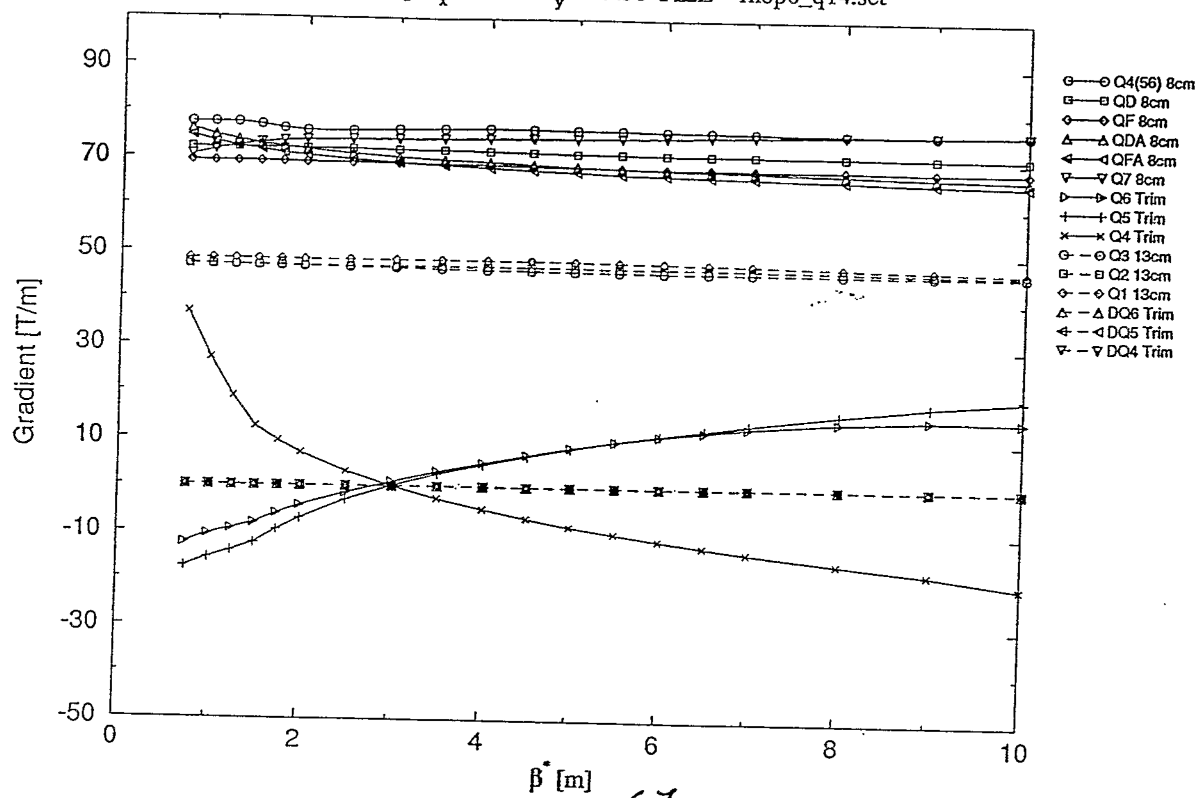


Fig 3-2: Insertion Quadrupole Gradients
[a] tune [3,3] [b] tune [4,4]

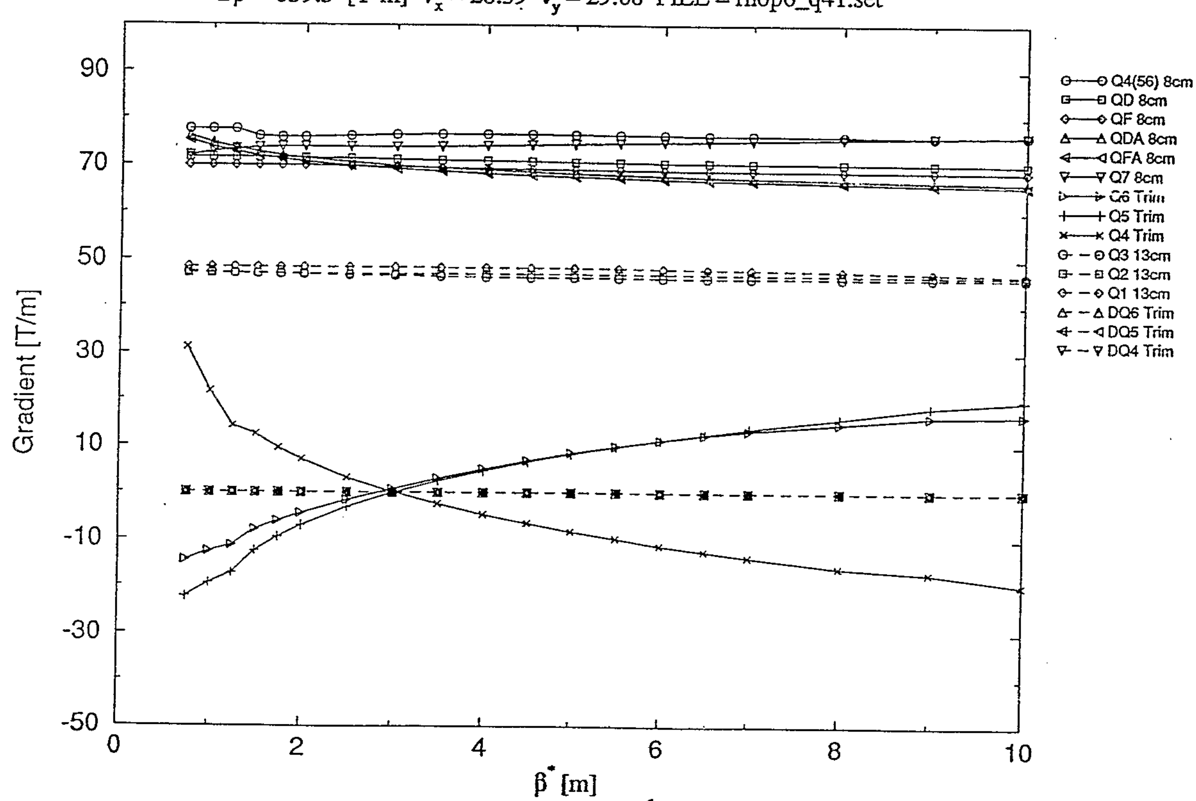
$B\rho = 839.5$ [T-m] $\nu_x = 28.09$ $\nu_y = 29.38$ FILE = rhop6_q14.set



[a]

Time: Tue Apr 5 15:39:29 1994 Last file modify time: Tue Apr 5 15:38:21 1994

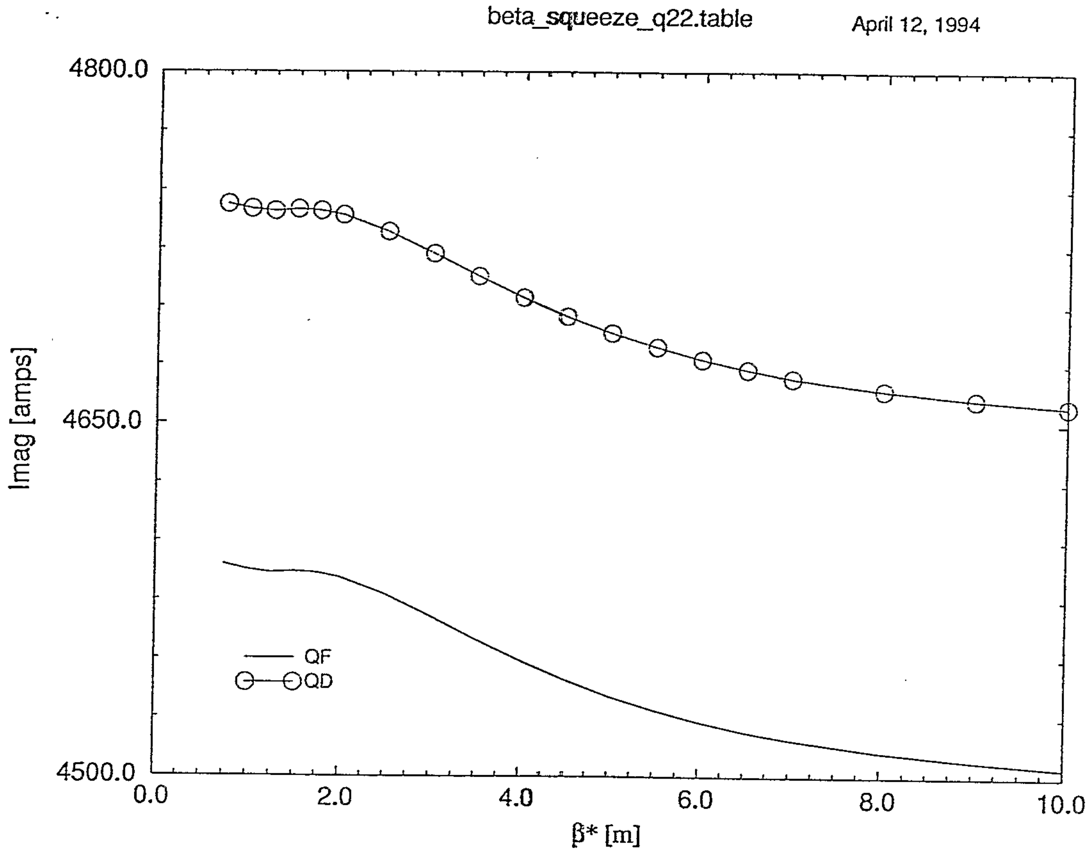
$B\rho = 839.5$ [T-m] $\nu_x = 28.39$ $\nu_y = 29.08$ FILE = rhop6_q41.set



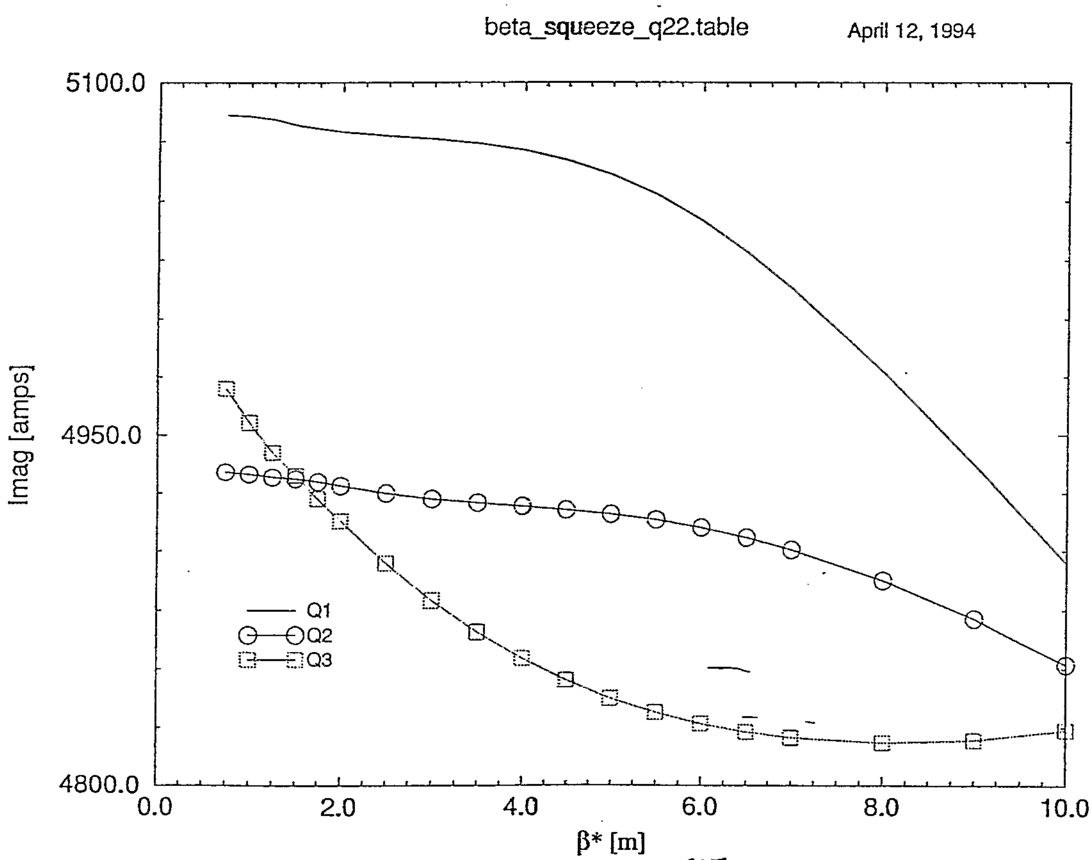
[b]

Time: Tue Apr 5 09:53:19 1994 Last file modify time: Tue Apr 5 09:51:49 1994

Fig 3-3: Insertion Quadrupole Gradients
[a] tune 14 [b] tune 41

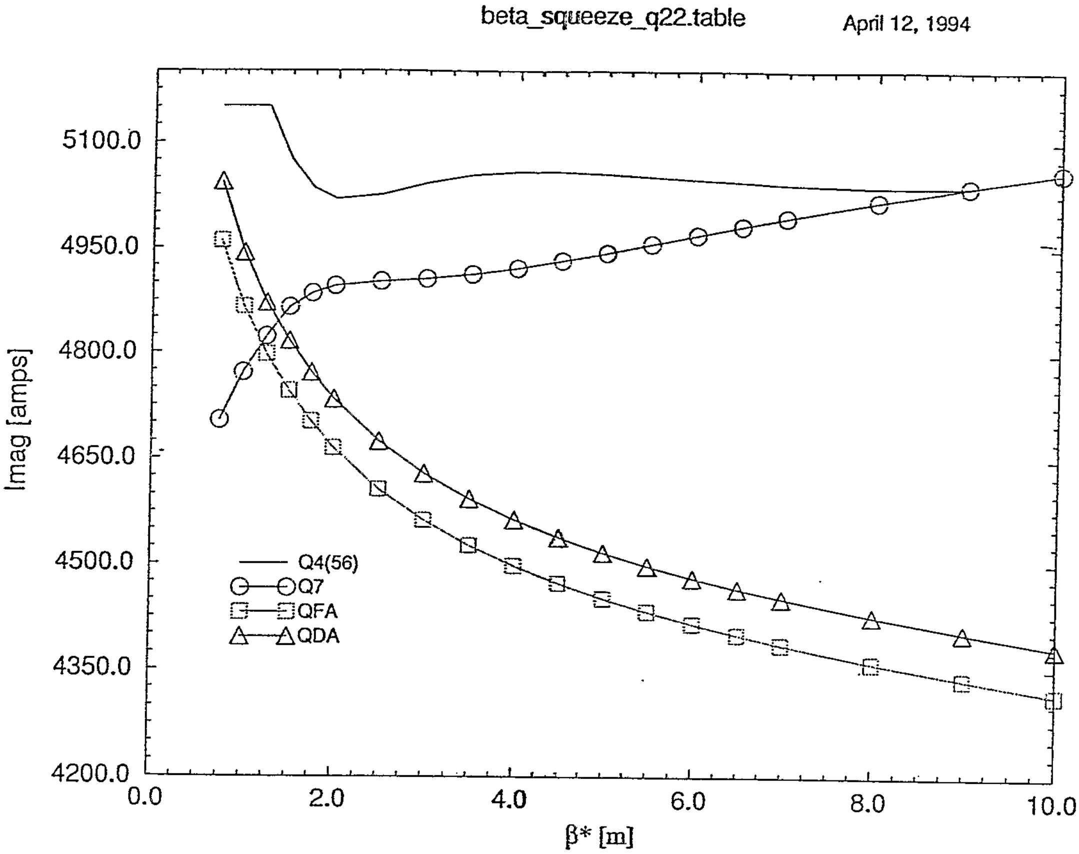


[a]

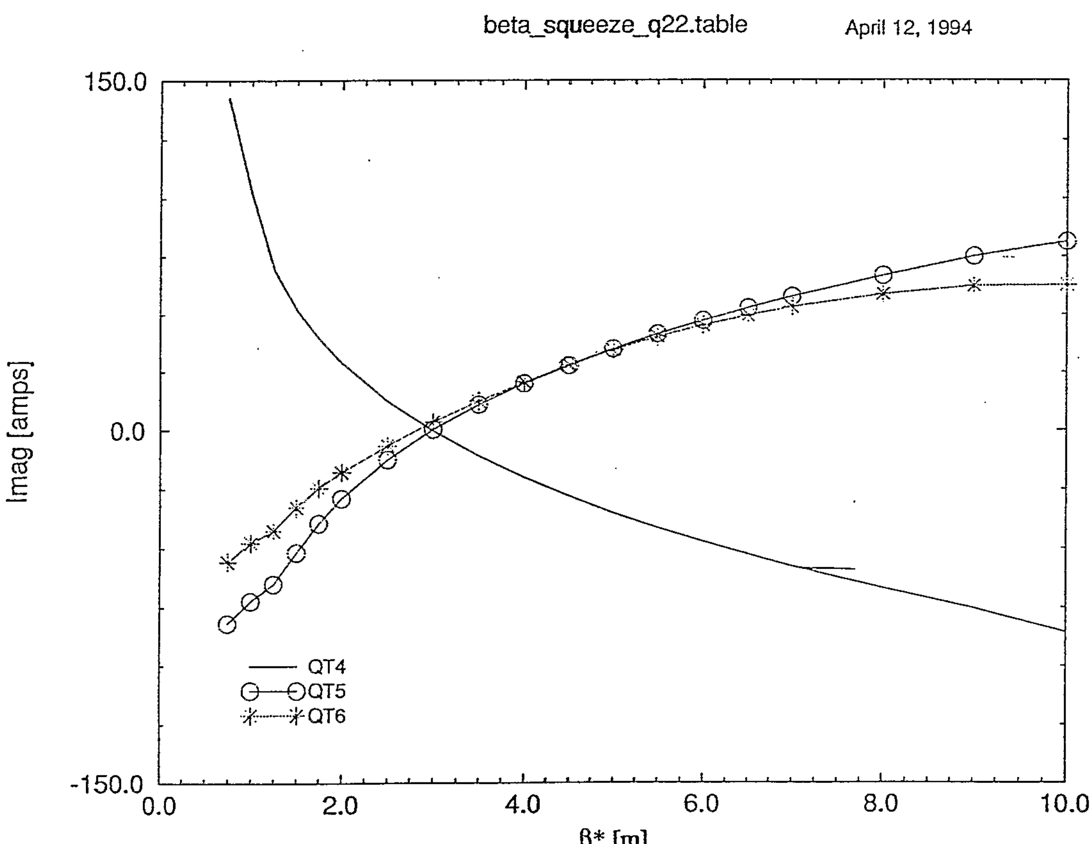


[b]

Fig 4-1: Quadrupole Currents at tune [2,2]
[a] Quads QF, QD [b] Quads Q_1, Q_2, Q_3



[a]



[b]

Fig 4-2: Quadrupole Currents at tune [2,2]
[a] Quads Q4(56), Q7, QFA, QDA [b] Quads QT4, QT5, QT6

```
Reading wire_up data from file wire_upn2.dat
Finished reading wire_up data from file wire_upn2.dat
nps = 12
ps_name = PS1 Imin = -155.000000 Imax = 155.000000
ps_name = PS2 Imin = -150.000000 Imax = 150.000000
ps_name = PS3 Imin = -450.000000 Imax = 0.000000
ps_name = PS7 Imin = 0.000000 Imax = 600.000000
ps_name = PSF Imin = 0.000000 Imax = 5500.000000
ps_name = PS(45)6 Imin = 0.000000 Imax = 700.000000
ps_name = PSQT4 Imin = -150.000000 Imax = 150.000000
ps_name = PSQT5 Imin = -150.000000 Imax = 150.000000
ps_name = PSQT6 Imin = -150.000000 Imax = 150.000000
ps_name = PSFA Imin = -150.000000 Imax = 150.000000
ps_name = PSDA Imin = -450.000000 Imax = 450.000000
ps_name = PSD Imin = 0.000000 Imax = 5500.000000

POWER SUPPLY MATRIX
1 1 1 1 1 1 0 0 0 0 0 0
0 1 1 1 1 1 0 0 0 0 0 0
0 0 1 1 1 1 0 0 0 0 0 0
0 0 0 0 0 0 1 0 0 0 0 0
0 0 0 0 0 0 0 1 0 0 0 0
0 0 0 0 0 0 0 0 1 0 0 0
0 0 0 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 -1 1 1
0 0 0 0 0 0 0 0 0 0 1 1
0 0 0 0 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1
0 0 0 1 1 1 0 0 0 0 0 0
0 0 0 1 1 1 0 0 0 0 0 0
0 0 0 1 1 1 0 0 0 0 0 0
Reading magnet data from file magcur_data
nst = 1 nmag = 14
bstar = 0.750000
magnet_name = Q1 I = 5086.083496
magnet_name = Q2 I = 4933.798828
magnet_name = Q3 I = 4969.964355
magnet_name = QT4 I = 142.917114
magnet_name = QT5 I = -81.903557
magnet_name = QT6 I = -55.804394
magnet_name = Q7 I = 4703.592285
magnet_name = QFA I = 4960.256836
magnet_name = QDA I = 5044.351074
magnet_name = QF I = 4589.975586
magnet_name = QD I = 4743.883301
magnet_name = Q4 I = 5150.846680
magnet_name = Q5 I = 5150.846680
magnet_name = Q6 I = 5150.846680
icase = 0
 POWER SUPPLY = PS1 CURRENT = 152.284668
 POWER SUPPLY = PS2 CURRENT = -36.165527
 POWER SUPPLY = PS3 CURRENT = -180.882325
 POWER SUPPLY = PS7 CURRENT = 113.616699
 POWER SUPPLY = PSF CURRENT = 4589.975586
 POWER SUPPLY = PS(45)6 CURRENT = 447.254395
 POWER SUPPLY = PSQT4 CURRENT = 142.917114
 POWER SUPPLY = PSQT5 CURRENT = -81.903557
 POWER SUPPLY = PSQT6 CURRENT = -55.804394
 POWER SUPPLY = PSFA CURRENT = 84.094238
 POWER SUPPLY = PSDA CURRENT = 300.467773
 POWER SUPPLY = PSD CURRENT = 4743.883301
owl 84:
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Fig 5: Output from 'ramp' code, giving wiring matrix, magnet currents and power supply currents

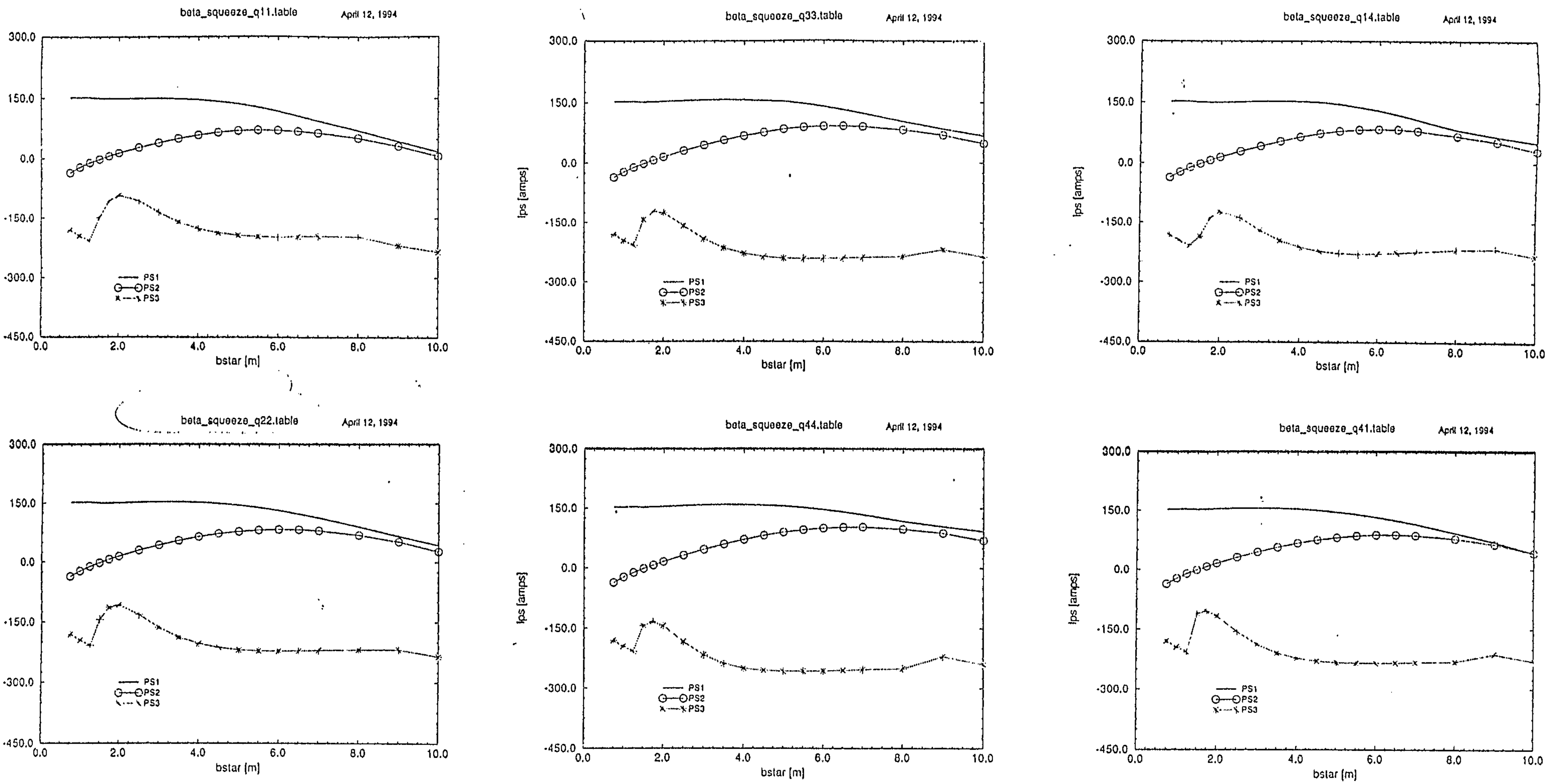

Fig 6-1: Power Supply PS1, PS2, PS3 currents for the six tunes in Fig 2

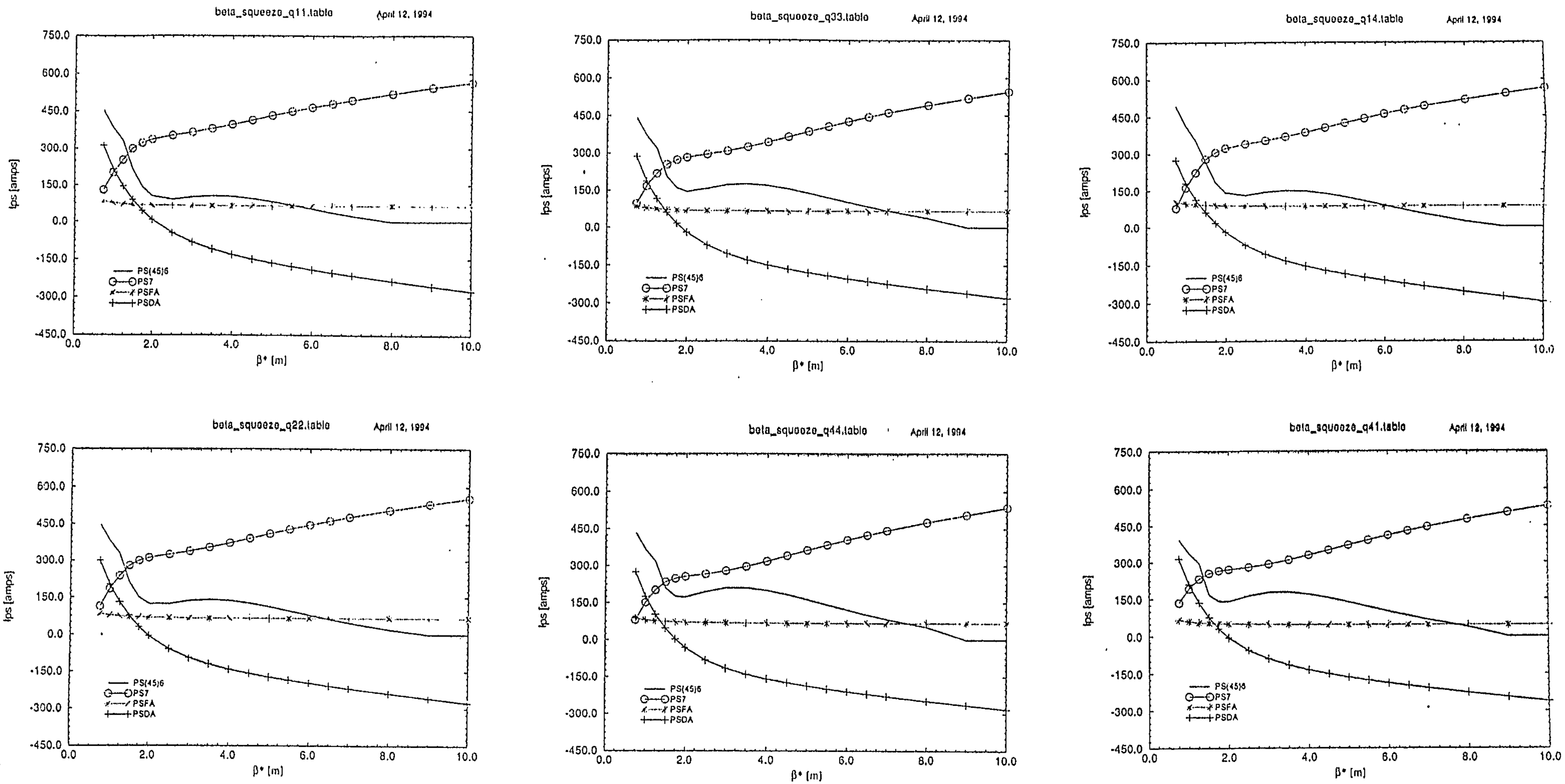

Fig 6-2: Power Supply PS(45)6, PS7, PSFA, PSDA currents for the six tunes in Fig 2

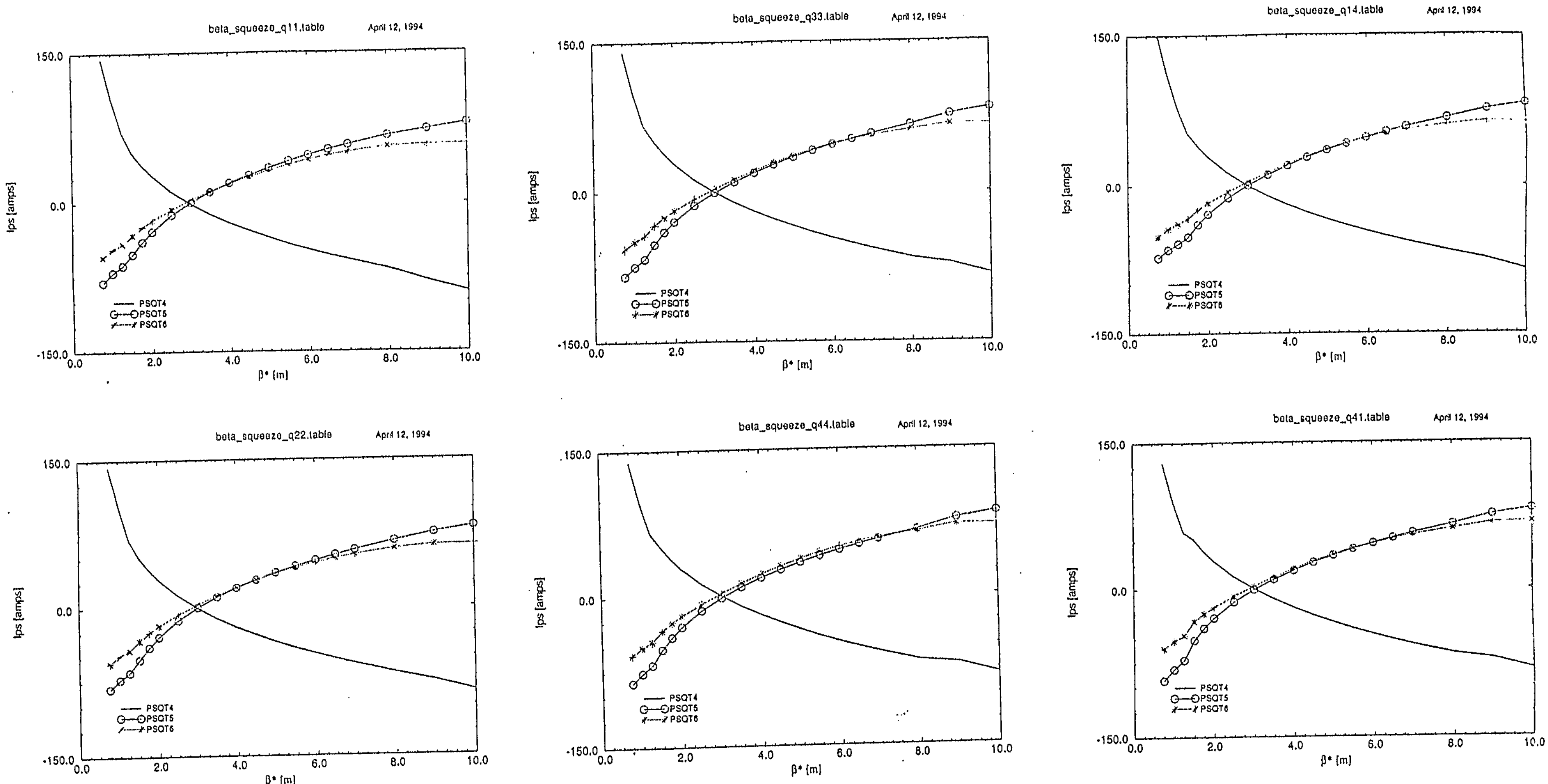

Fig 6-3: Power Supply PSQT4, PSQT5, PSQT6 currents for the six tunes in Fig 2

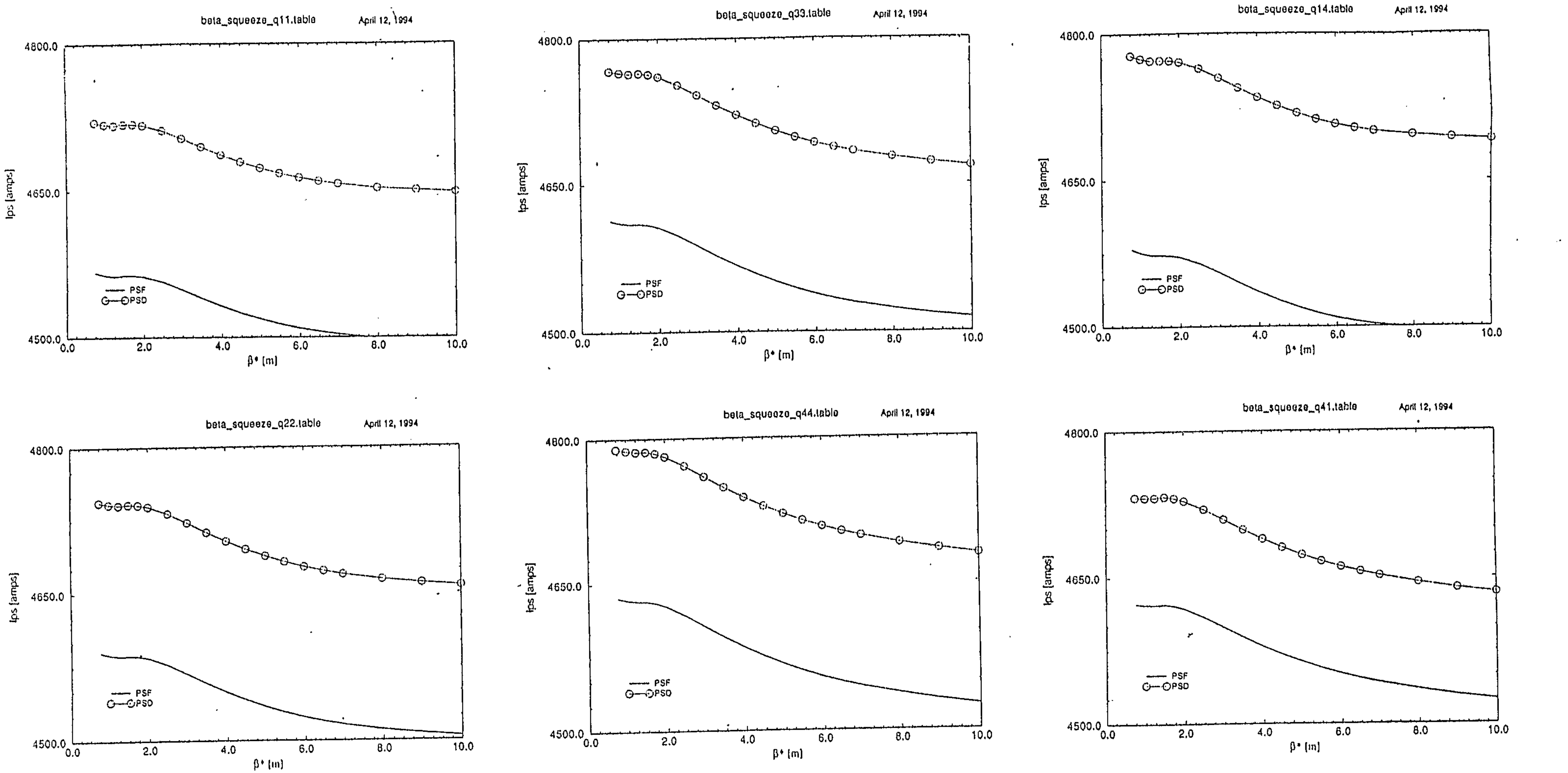

Fig 6-4: Power Supply PSF, PSD currents for the six tunes in Fig 2