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NATIONAAL INSTITUUT VOOR KERNFYSICA EN HOGE-ENERGIEFYSICA

NIKHEF–K / AmPS / 91-05

Required accuracy of tune measurement & parametrization of chromaticity control

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February 1991

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The betatron tunes ν_x and ν_y will be measured by Fourier-analyzing a BPM signal generated by a beam which received a fast (< 600 ns) kick. Alternatively, the tune can be measured by applying a (sinusoïdal) signal of varying frequency to a pair of deflectors; if the fractional part of (f_{kick}/f_{rev}) equals the fractional part of the tune, a beam blow-up can be observed. In this note the required accuracy of such a tune measurement is discussed.

tune

Knowledge of the tune when operating in Stretcher Mode is important, because (due to the large value of the chromaticity) relatively small changes in the tune will strongly influence the behaviour of the extraction process.

nominal value of tune: $\nu_x = 8.3000$

resonance value " : $\nu_r = 8.3333...$

corresponding energy difference (see eq. *(1)* below): $\delta = .0333.../-15 = -0.0022 = -0.22\%$.

Extracting the beam in monochromatic mode will require a controlled energy loss slightly in excess of the total energy spread |dE / E| of the stored beam. We expect dE/E = ± 0.05%, so the required energy loss may be something like 3 × 0.05% = 0.15%; the corresponding tune shift over this energy range is $|d\nu_x| = 15 \times 0.0015 = 0.0225$. Suppose we allow a 5% 'tune' error: 5% of 0.0225 ≈ 0.0010.

This means that the *absolute* accuracy of a tune measurement should be of the order of 0.0010.

Measuring the tune will probably occur first in Storage Mode. Since the damping time for energies $E > 400\ MeV$ is well below one second (see Table 2 of AmPS /88 – 11), we may assume that in this case the energy spread reaches its equilibrium value σ_ε. This value is proportional to the energy (see also Table 2 of AmPS /88 – 11). $\sigma_\varepsilon(500\ MeV) = 2.4 \times 10^{-4}$.

To measure the tune, the chromaticity should be set to zero, because the chromaticity–induced tune spread, $\delta\nu_x = \chi\sigma_\varepsilon$, is (much) larger than the error we allow in the tune measurement:

$\delta\nu_x\ (500\ MeV) = 0.0033$; $\delta\nu_x\ (700\ MeV) = 0.0050$

A procedure to control the chromaticity is given below.

chromaticity

The chromaticity χ expresses the energy-dependence of the tune:

$$\chi_z = \frac{(\nu)_z - (\nu_0)_z}{\delta}\ , \quad z = x, y\ ; \quad \delta = \frac{p - p_0}{p_0} \qquad (1)$$

This phenomenon exists in both transverse planes x and y; $\nu_o = \nu(p_o)$

The chromaticity is controlled by two families of sextupoles, **sch** and **scv**, located in the Curves. Sextupoles **sch** act predominantly (but not exclusively) on χ_x; similarly, the scv's act on χ_y. The chromaticity in the absence of any sextupole strength S_z ($[S_z] = m^{-3}$, z=x,y) is called the *natural chromaticity* χ_z^o. This suggest the following relation:

$$\begin{aligned} \chi_x &= \chi_x^0 + a_1 S_x + a_2 S_y \\ \chi_y &= \chi_y^0 + a_3 S_x + a_4 S_y \end{aligned} \qquad (2)$$

(with $a_2 < a_1$ and $|a_3| < |a_4|$)
If we put both chromaticities in a chromaticity vector $\boldsymbol{\chi}$, and both sextupole strengths in $\boldsymbol{S}$, then *(2)* can conveniently be expressed in the matrix form

$$\boldsymbol{\chi} = \boldsymbol{\chi}^o + \boldsymbol{A} \cdot \boldsymbol{S} \qquad (3)$$

where $\boldsymbol{A}$ is the 2×2 matrix containing the coefficients a_n. Inverting *(3)* yields an expression for $\boldsymbol{S}$ as function of $\boldsymbol{\chi}$:

$$\boldsymbol{S} = \boldsymbol{A}^{-1} \cdot (\boldsymbol{\chi} - \boldsymbol{\chi}^o) \qquad (4)$$

Numerical values for AmPS:

$\chi_x^o = -9.39$ $\quad a_1 = 4.05 \quad a_2 = 0.78$
$\chi_y^o = -9.51$ $\quad a_3 = -1.27 \quad a_4 = -2.44$

so *(4)* can be written as:

$$\begin{pmatrix} S_x \\ S_y \end{pmatrix} = \begin{pmatrix} 0.274 & 0.088 \\ -0.143 & -0.455 \end{pmatrix} \begin{pmatrix} \chi_x + 9.39 \\ \chi_y + 9.51 \end{pmatrix} \qquad (5)$$

or

$$S_x = 0.274\,(\chi_x + 9.39) + 0.088\,(\chi_y + 9.51) \qquad (6)$$
$$S_y = -0.143\,(\chi_x + 9.39) - 0.455\,(\chi_y + 9.51)$$

The predictions from parametrization *(6)* do agree with DIMAD results within a few 0.1% (which exceeds the normal calibration accuracy of the sextupoles) :

e.g. $\chi_x = +0.2$, $\chi_y = +0.2$ | eq. *(6)* -------> $S_x = 3.482$ (DIMAD: 3.484), $S_y = -5.789$ (DIMAD: -5.796)

e.g. $\chi_x = +15.0$, $\chi_y = +0.2$ | eq. *(6)* -------> $S_x = 7.537$ (DIMAD: 7.544), $S_y = -7.906$ (DIMAD: -5.906)

e.g. $\chi_x = -15.0$, $\chi_y = +0.2$ | eq. (6) -------> $S_x = -0.683$ (DIMAD: -0.686), $S_y = -3.616$ (DIMAD: -3.628)