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# OBSERVATIONS ON TUNE AND $\beta$ FUNCTIONS AT THE ATF DAMPING RING

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The precise measurement of the transverse tunes and their spectra is a basic demand in accelerator commissioning. It provides a simple access to lattice characterisation and validation of the optical model. This contribution describes recent improvements of the tune monitor system at the Accelerator Test Facility Damping Ring (ATF-DR) and the performance achieved. We present preliminary measurement results of beta functions, chromaticity, and dispersion on a relaxed optics with 90 degree horizontal phase advance per cell and compare these with the theoretical predictions.

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*Abstract*

The precise measurement of the transverse tunes and their spectra is a basic demand in accelerator commissioning. It provides a simple access to lattice characterisation and validation of the optical model. This contribution describes recent improvements of the tune monitor system at the Accelerator Test Facility Damping Ring (ATF-DR) and the performance achieved. We present preliminary measurement results of beta functions, chromaticity, and dispersion on a relaxed optics with 90 degree horizontal phase advance per cell and compare these with the theoretical predictions.

## 1 INTRODUCTION

The generation of extremely low emittance beams is a key characteristics of future linear colliders. It is essential in order to reach a luminosity of interest for high energy physics at TeV energies. The ATF [1], which consists of a 1.54 GeV S-band Linac [2] and a damping ring with strong focusing [3], is a test-stand for the critical components necessary to produce such beams. Started late 95, the S-band 1.54 GeV linac has successfully accelerated single bunch and multi-bunch beams with energy compensation, up to 1.3 GeV. The commissioning of the damping ring began in early 97 and has progressed smoothly. In spring 97, a single bunch of $6 \times 10^9$ electrons was stored at 0.96 GeV. In the following months the energy was raised to 1.255 GeV and the charge was increased to $9 \times 10^9$ electrons per bunch. During the early stage of commissioning some discrepancies between the calculated optical parameters and the measurements were observed for the design lattice with 135 degree horizontal phase advance per cell [4]. In October 97, the lattice was relaxed by reducing the phase advance per cell to 90 degree, in order to ease the operation and to simplify the comparison between measurements and model. In this paper we report recent modifications of the ATF tune monitor system and first measurements of Twiss parameters for the 90 degree lattice.

## 2 TUNE MEASUREMENT SYSTEMS

The beam position in the ATF-DR is detected by standard 4 buttons type beam position monitors (BPMs). For tune measurements, the signal of one BPM is passed through a fast sample and hold circuit which is synchronized with the bunch passage. After analog processing the signal is digitized turn-by-turn via a VEE system. The data is then acquired by a dedicated computer, which also performs the Fourier analysis and displays the results [5]. Previously, the number of revolutions sampled by this oscillation monitor was 500, providing a tune resolution of 0.002. Recently, this number was extended to 2000, yielding a resolution of 0.0005. In early 98, a second tune monitor system based on an FFT spectrum analyzer was installed, which uses the same analog signal, processing and synchronization, but which collects 3000 points, resulting in a resolution of 0.0003, or better with averaging, if the beam is stable enough.

During the initial commissioning, the tune was measured using the residual injection oscillations, which often necessitated to mis-steer the beam in order to produce a sufficiently large signal amplitude or coherence time. A second, more severe limitation was the sensitivity of the measurement to the incident beam position, the beam energy and to beam loss after injection, resulting in a measured tune slightly different from the actual tune of the stored beam. An additional disadvantage was the presence of strong synchrobetatron sidebands, sometimes stronger than the betatron sideband itself.

In order to determine the real tune values of the stored beam, in the absence of a dedicated exciter, we presently induce beam oscillations by shifting the bunch onto the rising edge of the (horizontal) extraction kicker, and rely on the betatron coupling of the ring to drive the vertical oscillations. By using a BPM at a location with small $\beta_x$ and large $\beta_y$, we could obtain an adequate signal for tune measurements in both planes. A drawback of this setup is the strong correlation between the vertical closed orbit and the coupling. In some cases, when the vertical orbit was small, we found that the vertical oscillations were too weak to give a satisfactory signal. Due to the averaging the spectrum analyzer then exhibited broad peaks and gave spurious results. Occasionally the measurement resolution was affected by strong synchrobetatron sidebands, possibly due to a head-tail instability.

## 3 REPRODUCIBILITY AND OPTICS MODEL

The tune reproducibility for a stored beam was recorded on different time scales, see Table 1: 15 minutes correspond, for example, to a series of measurements on the same ele-

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ment, 12 hours to a study session and one week to 4 different study sessions. The short term stability of the measurements was of the same order as the resolution, justifying the increase of resolution introduced early 98 and asking for further improvements.

| time | 15 min | 12 h | one week |
|---|---|---|---|
| $q_x$ | 0.0004 | 0.002 | 0.003 |
| $q_y$ | 0.0004 | 0.0015 | 0.002 |

Table 1: Reproducibility of the fractional tune measured for a stored beam over different periods of time; the resolution for a single measurement is 0.0003.

In 1997, discrepancies were found between the measured $\beta$ values and the theoretical optical model calculated from the magnet specifications by SAD [6]. Subsequently, the measured BPM response matrix was used to construct a new model, which includes fitted gradient errors for all quadrupoles magnets (see Fig. 1). The tunes predicted from this fitted model for the 90 degree lattice are 11.464 in the horizontal and 7.371 in the vertical plane, in excellent agreement with the fractional tunes measured on the spectrum analyzer (0.460 and 0.368) and on the oscillation monitor (0.464 and 0.369). By contrast, for the 135 degree design lattice studied in 1997, the measured and model tunes agreed only in the vertical plane, while horizontally a difference of 0.18 units remained unresolved [4].

## 4 $\beta$ FUNCTION MEASUREMENTS

All quadrupoles and combined-function bending magnets of the ATF-DR are equipped with trim coils allowing local gradient changes. Using the well known formula $\Delta q = \frac{1}{4\pi}\beta\ \Delta k$, one can calculate the value of the $\beta$ function from the tune variation $\Delta q$ produced by a change $\Delta k$ in the integrated focusing strength. The accuracy of the measured $\beta$ value is determined by the relative size of the measurement error $\delta q$ and the induced tune change $\Delta q$.

The measurement error $\delta q$ depends on the stability of the machine and on the resolution. To estimate $\delta q$, we recorded between each quadrupole measurement the "bare" tune and used its standard deviation $\sigma_q$ over the series of measurements to characterize the stability (compare Table 1).

The induced change $\Delta q$ is limited either by the strength of the trim coil power supply or by the optical perturbation introduced preventing the storage of the beam, for example, by pushing the beam onto resonances or by changing the injection trajectories.

The first measurements of the $\beta$ functions were performed in May 1997 for the 135 degree lattice [7]. These measurements used the trim coils of the arc quadrupoles family QF1R.x, located close to the bending magnets at low $\beta_x$, and on the QF2R.x family, located at the center of the regular arc cell, where $\beta_x$ is maximum. The unsatisfactory results at that time were explained by the poor resolution of the tune measurement.

Our recent studies focused on the 90 degree lattice, the model twiss functions of which are shown in Fig. 1. The $\beta$ measurements were performed in great detail on one half of the ring. Some points were also taken on the second half to check for symmetry. The results were as follows.

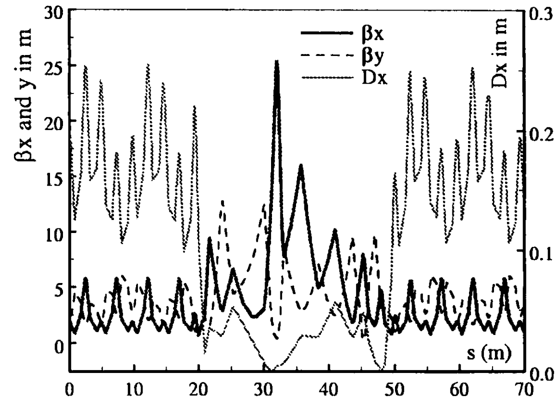

Figure 1: Model optics for one half of the ATF-DR.

Arc quadrupoles QF1R: the measured values were loosely related to the theoretical ones in both planes, possibly due to the small changes of tunes produced by the trim coils (of the order of 0.003 to 0.005) and to the resulting lack of accuracy in $\beta$.

Arc quadrupoles QF2R: the $\beta_x$ values were correlated to the SAD values (correlation coeffcient: 0.83). The $\beta_x$ values recorded on 2 different studies and the SAD calculation are compared in Fig. 2.

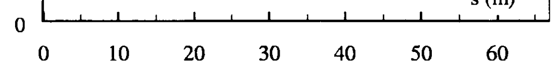

Figure 2: Local $\beta_x$ measurements at QF2R quadrupoles.

The averages of the measured local $\beta$ values can be compared with the $\beta$ values deduced from a global change of the main power supply of the arc quadrupoles. The results, in Table 2, show a good agreement between the averages and the global measurements for both families of quadrupoles, but up to 35% discrepancy between the measured and modelled $\beta$ at QF2R, which is not yet explained.

Straight sections: the QMR quadrupoles are powered in pairs. The two magnets of each pair are located at axially symmetric positions around the ring. By changing the corresponding power supply, we (globally) measure the average $\beta$ at the two locations. In both planes, the measured

|  | $\beta_x$ | $\beta_y$ |
|---|---|---|
| QF1R ave. local meas. | $2.16 \pm 0.68$ | $3.17 \pm 0.77$ |
| QF1R global meas. | $1.88 \pm 0.10$ | $3.09 \pm 0.15$ |
| QF1R model pred. | 2.26 | 3.57 |
| QF2R ave. local meas. | $5.51 \pm 0.51$ | $2.93 \pm 0.60$ |
| QF2R global meas. | $4.95 \pm 0.14$ | $3.03 \pm 0.09$ |
| QF2R model pred. | 3.69 | 2.24 |

Table 2: Comparison of measured local $\beta$ averages, global $\beta$ measurements, and model predictions.

|  | rel. change | measured | ideal | fitted |
|---|---|---|---|---|
| $\Delta\xi_x$ | $\Delta k_{SF} = 3.4\%$ | $0.9 \pm 0.6$ | 1.2 | 1.4 |
| $\Delta\xi_y$ | $\Delta k_{SD} = 2.9\%$ | $2.4 \pm 0.5$ | 2.7 | 2.5 |

Table 3: Variation of chromaticity with sextupole strength: measurement and predictions for ideal and fitted model.

averages agree well with the calculation. A few individual trim power supplies allow us to perform local measurements as well. Their results are consistent with the measured averages and do not reveal a large asymmetry. Figure 3 shows $\beta$ values for the horizontal plane.

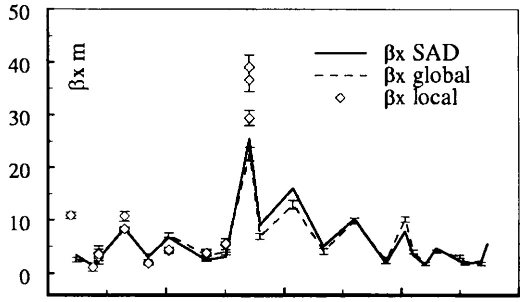

Figure 3: Global and local $\beta_x$ values in the straight section.

## 5 CHROMATICITY

The ring chromaticity can be determined from the shift in betatron tune with rf frequency, using the relation $\xi_{x,y} = -\alpha_c f_{rf} \Delta q_{x,y} / \Delta f_{rf}$, where $\alpha_c$ is the momentum compaction factor ($\alpha_c \approx 0.00473$ in the model) and $f_{rf}$ the rf frequency. From the measured slopes of $q_{x,y}(f_{rf})$, we estimate $\xi_x \approx +2.6$ and $\xi_y \approx -0.4$. The positive chromaticity in the horizontal plane appears to be necessary to avoid beam loss, caused by a head-tail instability. Table 3 compares the measured dependence on the sextupole excitation with predictions for the ideal and the fitted optics.

## 6 DISPERSION

The dispersion in the ATF-DR is measured by detecting the orbit change induced by a change in rf frequency. At injection the ring rf frequency has to be synchronized with the linac rf. Starting a few 100 $\mu$s after injection, the rf frequency is ramped by 10 kHz over a time period of 50 ms. The orbit is measured about 10 ms after the end of the frequency ramp. These times are of the same size as the longitudinal damping time (about 40 ms), which may introduce a systematic measurement error. Note that the observed orbit change is proportional to ($\eta\ \Delta f_{rf}/\alpha_c$), so that we cannot easily distinguish deviations in $\eta$ and $\alpha_c$.

Figure 4 compares the measured dispersion functions with those calculated using the fitted model. The residual vertical dispersion is close to zero; the average horizontal dispersion is about 20% percent smaller than the model calculation, perhaps indicating a systematic measurement error, *e.g.*, due to a nonadiabaticity of the frequency ramp.

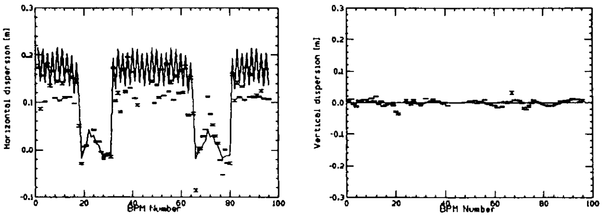

Figure 4: (Left) horizontal and (right) vertical dispersion; measurement (symbols) and model (lines).

## 7 CONCLUSIONS

The measured and calculated $\beta$ functions show a good agreement in the straight sections, while in the arcs measurements and model differ by up to 35%. The measurement of the vertical beta function was hampered by the absence of a vertical excitation. It is still lacking resolution in both planes for the single-shot measurements. The observed variation of chromaticity with sextupole strength is roughly consistent with the fitted model and confirms the absence of gross optical errors. The measured arc dispersion is about 20% lower than calculated.

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