Energy Ramping in ELETTRA

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Abstract

The paper introduces the schemes developed to perform energy ramping in the ELETTRA storage ring and reports on the results of the operation carried out so far.

1. INTRODUCTION

ELETTRA is a low-emittance electron storage ring operating as a light source in Trieste, Italy [1]. The commissioning of the machine had started in October 1993 [2]. The accelerator complex consists of a linac, a transferline and a storage ring. One of the distinct characteristics of ELETTRA is the variable energy of the storage ring in a wide range from 1.1 to 2 GeV. A challenging issue for ELETTRA has therefore been to perform energy ramping with high efficiency and reliability maintaining the low-emittance characteristics of the beam as well as guaranteeing the reproducibility, both of which are essential for the new generation light sources.

The developed energy ramping scheme basically consists of: (i) The high level software that interfaces the operator and the machine and create, according to the operator's request, a set of data of the magnet currents which specifies the path from the initial to the final state along which ramping will be performed. (ii) The stepwise synchronisation of the DAC settings on the power supplies with the data set produced in (i) which is executed by the control system [3]. (iii) The tune feedback system which keeps the transverse tunes constant during ramping using a pair of quadrupole families [4].

In the following, we shall describe the main features of the developed scheme and review the entire ramping operations performed heretofore.

2. RAMPING SCHEME

Energy ramping and file ramping.

Energy ramping in the ELETTRA storage ring may be described as preparing an array of current composed of N elements for each power supply family, and applying simultaneously the jth value ($1 < j \leq N$) of each array on the corresponding power supply, thus arriving to a new state with higher energy while keeping the identical optics. The relation among all jth elements is fixed by the dipole current that determines the beam energy. The synchronisity of the setting guarantees the transition to the next state without any undesirable deviation in the optics. The number of steps N is determined from the characteristics of the power supplies.

The above procedure can be viewed as a special case of the general scheme where the relation among the jth elements may be determined by other constraints. An extension to what we call as file ramping was thus made which enables a general smooth transition from one optics state to another. Two files containing the magnet current data respectively of the initial and the final state become the input which may differ not only in energy but also in the optics.

While the path on which to ramp is obvious for energy ramping, it is somewhat arbitrary for file ramping. We have decided to treat both cases as equally as possible. Namely, the dipole current has been taken as the common reference parameter. In any ramping procedure, the dipole current increment per step is taken as constant. At a given step, the energy corresponding to the dipole current is firstly calculated. In case of pure energy ramping, the gradients and fields are linearly scaled to the new energy and then the corresponding currents are calculated. In case of file ramping, the normalised magnet strengths are first scaled linearly from the initial state to the final state given by the file. Then, using the energy given by the dipole current, the corresponding currents are calculated. This procedures ensures the most general file ramping to be done consistently while still keeping the dipole current as the reference parameter. In addition, the optics from the machine physics point of view is still ramped in a linear way, providing thus the smoothest path from one file to another.

Synchronisation scheme.

The synchronisation of the DAC setting on the power supplies is achieved by the control group of ELETTRA by developing a general purpose distributed synchronisation system, which is completely integrated in the ELETTRA control system [3]. The designed system fully utilises the MIL-1553B field bus which had been already incorporated into the lower level network. The arrays of magnet currents prepared on the high level are sent down to the Equipment Interface Units (EIUs). The synchronised setting is triggered by the broadcast packets sent from the Local Process Computers (LPCs). A detailed description is found in Ref. 3.

Tune feedback system.

In prevision of eventual betatron tune variations during the ramping, the tune measurement system has been designed to allow a tune feedback [4]. The feedback is accomplished via software and the corrections are done by acting on the power supplies of the two quadrupole families placed in the dispersive arc. The choice of the two families was based on their decoupled effects in the two planes and their supersymmetric arrangement around the ring. The latter guarantees avoiding the creation of new resonance stopbands due to the breaking of the optical supersymmetries. The algorithm for the feedback is based on a forward correction scheme for which the correction to apply depends on all the past history [4]. This choice was found to be the most appropriate to obviate both the energy dependence of the system and to be able to compensate within the specifications the large vertical tune variation encountered in the energy above 1.7 GeV. The feedback has revealed capable to keep the betatron frequencies within 1 kHz from the reference value.

Other aspects.

Unlike the fields and their derivatives, the currents cannot be scaled linearly due to saturation effect which also differs among the power supplies, the largest in ELETTRA being the dipoles. Therefore all scaling is done on the level of fields and gradients, which are calculated from the currents using third or fourth order polynomials [5]. The calibration coefficients have been obtained from fits to measurements to a precision of up to 2×10^{-4} in the range from 1.1 to 2 GeV.

The number of steps and the speed in ramping are limited by the behaviour of the power supply, which in ELETTRA is equipped with the 16 bit DACs. It was decided not to exceed one bit per step for dipoles, whose speed was limited to 10 msec per step. The changes in bit for each power supply, in energy ramping from 1.1 to 2 GeV with the nominal optics

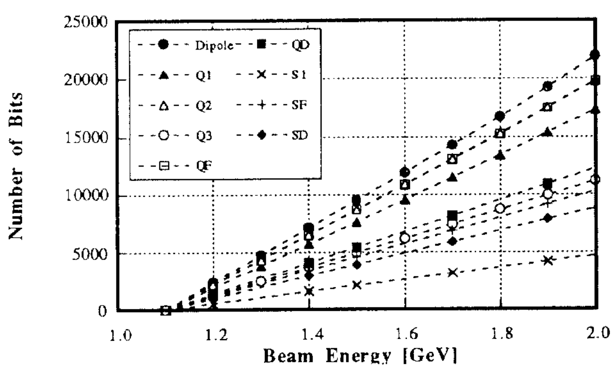

Fig. 1. Number of bit versus energy.

are illustrated in Fig. 1. The maximum change is seen to occur with dipoles indicating that other power supplies experience changes less than one bit per step. Relative field errors due to the ambiguity in single bit are estimated to be less than 10^{-4} with an exception of a sextupole family having 1.8×10^{-4}, thus being well below the tolerance level. The curves in the figure also confirm the good linearity of the magnets over the considered range. With the maximum speed of 10 msec per step and the number of bits read from the figure, the time required to ramp from 1.1 to 2 GeV is calculated to be 3.5 minutes.

In view of an extended operation in future, the ramping of the rf voltage is also incorporated in the control system. With the amount of changes in the beam parameters under the normal conditions (Table 1), however, the ramping of the rf voltage is not found to be necessary between 1.1 and 2 GeV with use of the amplitude loop of the cavity voltage [6].

Table 1. Beam parameters with 1.05 MV rf voltage.

Energy (GeV)	1.1	2.0
Synchronous phase (deg)	1.3	14.2
Synchrotron frequency (kHz)	11.8	8.6
Natural bunch length σ_L (mm)	2.8	7.0
Energy acceptance $\varepsilon_{max}/\sigma_\varepsilon$	65.6	21.9

3. ACTUAL OPERATION

The very first energy ramping was carried out without use of tune feedback where 10 mA of beam current was successfully taken up from 1.1 to 1.6 GeV, with the measured lifetime of 7.1 hours. Continuing the ramping, a rapid beam loss was encountered when the energy reached 1.96 GeV. Measurements of the machine in steps of 100 MeV showed large variations in the betatron tunes while the lifetime, the orbit, the chromaticities and the dispersion remained reasonably constant, suggesting that the beam loss at 1.96 GeV was due to the vertical tune hitting the integer resonance.

The tune feedback was introduced in the subsequent ramping which managed to keep the two tunes constant from the first stage. In this way, it was possible to take a beam up to the maximum achieved value of 2.31 GeV. Unlike ramping without feedback, the residual chromaticities were observed to increase notably above 1.9 GeV, with the maximum measured values of $\xi_{x,y}$ = (3.1, 4.5) at 2.27 GeV. Synchrotron frequencies measured as a function of energy showed an overall agreement with the expectation in their reduction with energy. The implementation of file ramping routine followed a month later giving successful results on the test.

Upon inspection, it was soon noticed that the observed large tune shifts above 1.6 GeV are due to deviation of the field index of the combined function dipoles from the nominal value, which explains also the optical distortion being larger vertically due to its large beta function in the dipoles. The

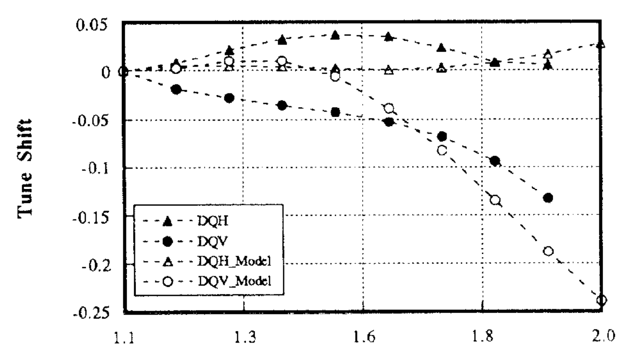

Fig. 2. Variation of betatron tunes with energy.

comparison in the tune shifts between the measurement and the model is shown in Fig. 2. Similar agreement is obtained also in the chromaticities and in the required changes in the quadrupole pair to restore the original tunes.

Since energy ramping excessively relies on the tune feedback system bringing changes in the quadrupoles as much as 4% at 2 GeV leading to a substantial optical distortion, it turned out necessary to perform file ramping by preparing files with a compensated optics in the high energy region. The rematching of the optics was made by adjusting the quadrupole pair in the dispersive section to recover the achromatic condition, followed by the tune matching using two of the quadrupole triplet in the dispersion free section. Files were created in step of 100 MeV above 1.7 GeV where the distortion starts to become serious. File to file ramping was then performed with the files created from 1.1 to 2 GeV without using the tune feedback, and updated the files after making a fine adjustment of tunes at each step. File ramping via updated files was subsequently carried out turning on the tune feedback. As expected, the results showed a large improvement in lowering the load of the tune feedback where the large quadrupole current change was reduced nearly by a factor of 15. The measured dispersion averaged over the

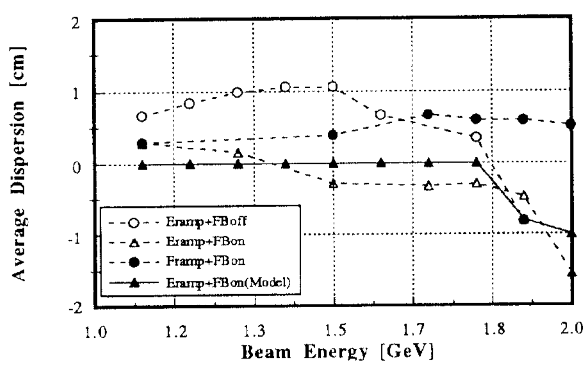

Fig. 3. Average dispersion versus energy.

BPMs in the dispersion free sections shows (Fig. 3) an expected improvement over the previous energy ramping cases whose behaviour near 2 GeV is in agreement with the model. Chromaticities were observed to improve as well.

In course of the studies it became clear, however, that the closed orbit distortion which increases during energy ramping is not caused by the optics distortion, as we see a good agreement in the measured average horizontal orbit between energy ramping and file ramping (Fig. 4).

As the negative sign of the average indicates, the orbit around 2 GeV was observed to be dispersive, implying a mismatch in the path length, the reason of which is not yet understood. As the shift can be observed also with low beam current, it would be more reasonable to attribute the effect to a mismatch in the corrector settings. The investigation in connection with the introduction of the orbit feedback is in progress.

The reproducibility of the machine state after ramping together with the speed performance was tested by carrying out energy and file ramping with the speed of respectively 20 and 10 msec per step. Ramping with 10 mA beam from 1.1 to 2 GeV was repeated, cycling the magnets in between. The comparison between two consecutive rampings shows changes in the betatron tunes to less than 0.002, and in the

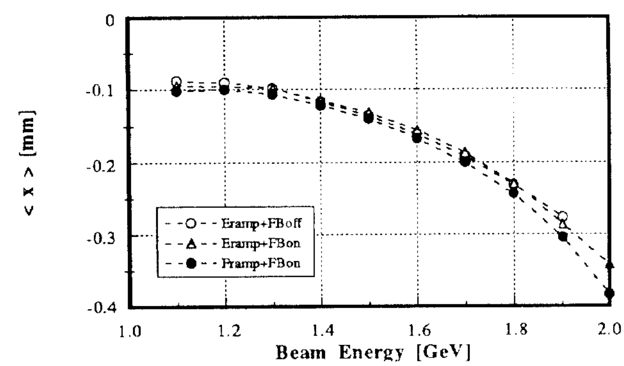

Fig. 4. Variation of horizontal average orbit with energy.

orbit statistics to less than 10 μm, in all cases, demonstrating a sufficiently good reproducibility. Practically no beam loss was noticed during ramping with the maximum speed which takes 3.5 min from 1.1 to 2 GeV.

Ramping up to 2 GeV has already become a routine operation for the user's experiments. The residual orbit distortion at the final energy is compensated in the insertion devices with local bumps before closing the gaps. The lifetime tends to improve with energy in the low current regime while it is contrary in the high current regime, suggesting that the lifetime is dominated by the Touschek scattering at low current while the gas desorption predominates at high current. The transverse beam size measured with nearly 10 mA of beam current with the synchrotron radiation profile monitor [7] shows an overall linear increase with energy horizontally whose slope giving the expected order of magnitude for the emittance, while vertically it seems to stay constant.

4. REFERENCES

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