OPERATION OF THE ESR (GSI,DARMSTADT) AT THE TRANSITION ENERGY

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Abstract

For the precise determinations of masses of short lived nuclei the experimental storage ring (ESR) of the GSI (Darmstadt) can be used as an energy isochronous time-of-flight (TOF) mass spectrometer.

A new operation mode of the ESR was investigated. At the ESR the 'isochronous' mode (when γ=γ_{tr}) can be obtained by increasing the average dispersion function in the dipole magnets up to 17.2 m. Its properties were studied in beam times with Ca^{20+} ions at the energy 370 MeV/u. For these ions a γ_{tr} - parameter equals to the relativistic γ-factor could be reached.

1 INTRODUCTION

The Experimental Storage Ring of the GSI Darmstadt is used for accelerator, atomic and nuclear phisics experiments. The ring with 108.6 m circumference has a maximum rigidity of 10.8 Tm. It is proposed the ESR can be used as an isochronous time-of-flight mass determination of rapidly decaying nuclei [1]. Secondary beams of radioactive nuclei far from β-stability are produced by using high-intensity heavy ion beams provided by the SIS accelerator. The nuclear fragments can be mass analysed by the fragment separator (FRS) and injected into the ESR using single turn injection. In order to determine the mass of these ions the following relation between the mass resolution $\Delta m / m$, the time resolution $\Delta T / T$ and the velocity spread $\Delta v / v$ of the ion circulation in the ring is valid:

$$\frac{\Delta m}{m} = \gamma_{tr}^2 \frac{\Delta T}{T} + (\gamma_{tr}^2 - \gamma^2)\frac{\Delta v}{v} + \gamma^2 \frac{\Delta B}{B} \qquad (1)$$

where $\gamma=(1-(v/c)^2)^{-1/2}$, γ_{tr} is the value of γ at the transition energy, which is a constant for a certaing tuning of the ring. At γ=γ_{tr} the relationship for the mass resolution no longer depends upon the inherent momentum spread of the injected particles. Although it is possible to achive very small momentum deviations using electron cooling, the cooling time ($\approx 1s$) restricts the lifetime of the nuclei to be studied. An alternative method is to change the optic in order to reach the condition γ=γ_{tr} [2,3]. This method provides the possibility of mass measurements for fast decaing nuclei far in the unsteable region with a lifetime in the ms region. It is indended to use this method for precise mass determination of radioactive fragments that injected into the ESR. The mass indentification itself will be performed in the ESR by means of a time of flight measurements with a high time resolution.

2 ION OPTICAL CALCULATION

Whereas the usual injection energy of the ESR (200-400 MeV/u) corresponds to a γ value of about 1.40. The 'standart' beam optics is defined by a γ_{tr} of 2.76. In oder to achieve the condition γ=γ_{tr} at realistic injection energies the modification of the ring optic has to be done.

To reach the required reduction of the γ_{tr}, according to the relation

$$\frac{1}{\gamma_{tr}^2} = \frac{1}{C}\oint \frac{D(s)}{\rho} ds \qquad (2)$$

(where D is the dispersion function, C is the circumference and ρ is the radius of curvature of the central orbit) the average value of the dispersion function in the dipole magnets of the ESR (ρ =6.25 m, C=108.6 m) has to be increased up to 17.2 m.

Detailed ion optical calculation with the computer code MIRKO have been performed to determinate the set values of the ESR quadrupoles for this special mode of operation. For the experiments performed at the ESR a solution had to be found, which has to take varios restriction of the ESR into account [4].

- The value γ_{tr} of the ring should not be large. Ions with γ-values have large magnetic rigidity ($B\rho$-value), espesially neutron rich exotic nuclei require a large bending power, because of their small Z/A values. The maximum $B\rho$-value of the ring, however, is limited to 10 Tm.
- The number of betatron oscillations in horizontal and vertical directions should not be integer.
- Chromaticity values are requested not to be large to achiev the momentum stability.

- Ion beams coming from the FRS should be kicked into a stable orbit while they make the first turn in the ring. For this purpose it is neccessary to use an injection septum and a magnetic kicker presently available. The bending angle of the kicker must be within 3-5 mrad.
- To match the detector size (40 mm in diameter) the beam diameter and also the dispersion at the time pick off detector should not be large.
- Particle collisions with the injection septum on the stable beam orbit have to be excluded.

The setting of the ESR has superperiodicity of 2 having east-west and north-south mirror symmetric arrangement. The ion optical flexibility is obtained mainly by supplying 10 pairs of quadrupoles independently of each other. By this way 8 parameters of thre lattice function ($Q_{h,v}, Q'_{h,v}, \beta_{h,v}, \beta'_{h,v}, D, D'$) can be varied at several important locations of the orbit. It was possible to calculate a series of settings ranging from γ_{tr}=2.76 down to 1.0 maintaining the former symmetry of the ESR quadrupole settings. The resulting β-functions are shown in fig.1.

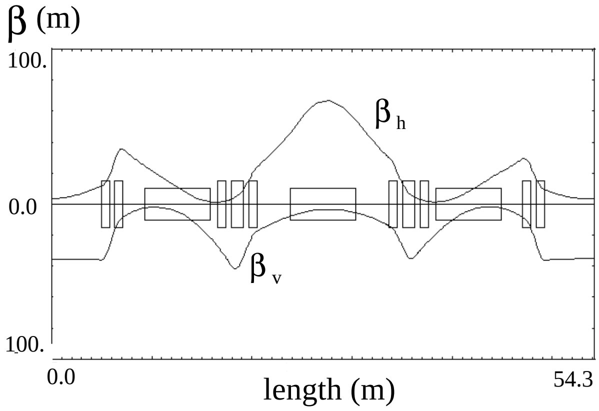

Figure 1. Calculated β-functions for one superperiod of the ESR mode with γ_{tr}=1.40.

3 INJECTION OF THE ION BEAM AT γ_{tr}=1.40

The calculated settings of the ESR for low γ_{tr} were tested. It was possible to inject the ion beam at $\gamma=\gamma_{tr}$ at an injection energy of 370 MeV/u corresponding to a γ_{tr}=1.40. It should be noted that the isohronous mode allows all ESR quadrupoles to be operated with their 'standart' polarity. The beam is put into a stable orbit during the first turn by using the injection septum and the kicker without destroing the isochronous condition of the ring. After one turn the ions come back to the injection point but go throught this point without being intercepted by the septum and are not affected by the kicker any more [5].

4 MEASUREMENTS OF LATTICE PARAMETERS

The experimental determination of the γ_{tr} parameter was performed by measuring the variation of the revolution frequency as a function of the beam momentum p which can be defined by the high voltage U of the electron cooler:

$$\frac{\Delta f}{f} = \eta \frac{\Delta p}{p} = \eta \frac{\Delta U}{U} \frac{\gamma}{\gamma + 1} \qquad (3)$$

where the parameter η is defined as

$$\eta = \frac{1}{\gamma^2} - \frac{1}{\gamma_{tr}^2} \qquad (4)$$

For a defined ion energy the relativistic parameter γ is exactly known and frequencies were measured with high accuracy via a Schottky noise analysis. The measurements were curried out in the standart mode and in series modes where the transition parameter has different value. Fig.2 shows a comparison of the transition parameter between experimental and theoretical values calculated with the computer cod MIRKO for series of the ESR settings.

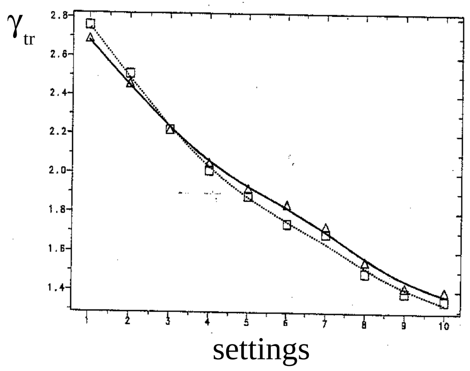

Figure 2. Measured and calculated γ_{tr} parameter for series of the ESR settings (Δ –experiment, □ - theory).

Measured and calculated horizontal and vertical tunes (Q_h,Q_v) for different γ_{tr} are given in the table 1.

Measured Schottky spectrums at the ESR mode with γ_{tr}=1.40 have the same width for both cooled beam and uncooled beam (fig.3); the basis frequency in these measurements was set to 50 MHz. As given by formula (4) for the standard mode an η value equals 0.376.

Table 1. Measured and calculated betatron oscillation for different γ_{tr}.

γ_{tr}	$Q_{h,v}$		$Q_{h,v}$	
	Theory		Experiment	
2.76	2.27	2.15	2.31	2.32
2.22	2.29	2.53	2.33	2.67
1.93	2.26	2.59	2.39	2.61
1.71	2.22	2.69	2.35	2.74
1.34	2.18	2.74	2.17	2.76

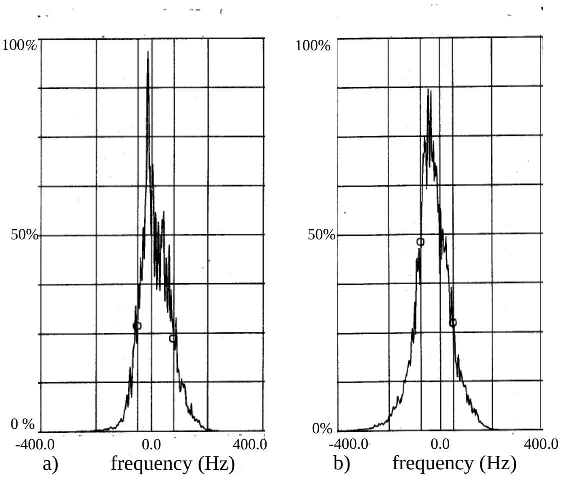

Figure 3. a) Schottky spectrum for a Ca^{20+} cooled beam at the ESR mode with $\gamma_{tr} \approx \gamma$; b) Schottky spectrum for the same beam without cooling at the ESR mode with $\gamma_{tr} \approx \gamma$.

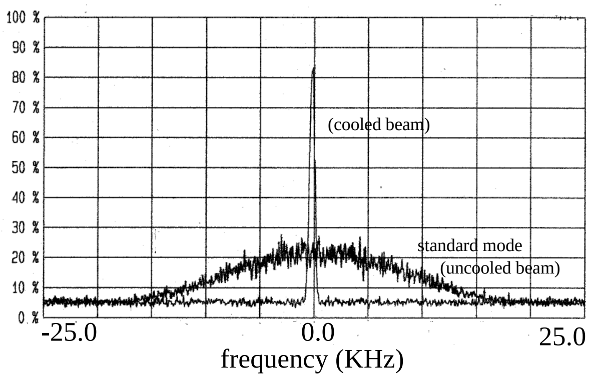

Figure 4. Schottky spectrums for a Ca^{20+} uncooled beam at the standard mode of the ESR and for a cooled beam.

The measured frequency spectrum is compressed by a factor of about 100 compared to the standard mode (Fig.4). It means that the measured parameter η is $3.76*10^{-3}$ and the transition parameter γ_{tr} equals 1.404. It was not possible to reach condition $\eta=0$ because of the intrabeam scattering. But as it was shown for protons at NAP-M in Novosibirsk that intrabeam scattering is strongly suppressed for sufficiently small ion current if lattice of the storage ring tuned to the isochronism condition and strong cooling is applied [6]. This means that it is really to reach $\eta=0$.

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