OPERATION OF THE ESR AT TRANSITION ENERGY

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Abstract

At the GSI storage ring ESR an isochronous ion-optical setting of the lattice has been developed and studied recently. This setting is characterized in particular by a low value of the transition energy corresponding to a relativistic gamma-factor of approximately 1.37. Contrary to the standard mode of ESR-operation, where the transition point is in the vicinity of 2.5, this setting allows to inject and to store heavy ion beams at an energy that equals the transition energy of the lattice. The characteristics of this mode of ESR-operation have been studied experimentally and the results of these studies are discussed. One of the possible applications is the time-of-flight mass spectrometry of short lived nuclear fragments. Results of first tests are presented.

1 ESR-OPERATION AT TRANSITION ENERGY

The Experimental Storage Ring ESR is described in [1]. Here we want to emphasize the possibility to inject not only stable beams from the SIS [2], but also secondary heavy ion beams via the FRS [3].

The operation mode we are reporting on is doubly symmetric although only one of the symmetry axes is given by power supplies.

If the ESR is operated at transition, the revolution frequency f becomes velocity independent to first order:

$$\frac{\delta f}{f} = \left(\frac{1}{\gamma^2} - \frac{1}{\gamma_t^2}\right)\frac{\delta p}{p} \qquad (1)$$

γ = relativistic Lorentz factor

γ_t = transition point

as the term in parentheses vanishes [4]. For that reason this mode of operation is called isochronous.

Because of the magnetic rigidity limit (10 Tm) of the ESR, the transition point had to be reduced with respect to the commonly used setting. Due to the relation

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

where ρ is the radius of curvature of the orbit and C is the circumference of the ESR, the dispersion $D(s)$ in the arcs had to be increased in order to decrease the value of γ_t to approximately 1.4. This corresponds to magnetic rigidity values within the ESR limits even for secondary beams far off β-stability with large values of the mass-to-charge ratio m/q. Some boundary conditions had to be taken into

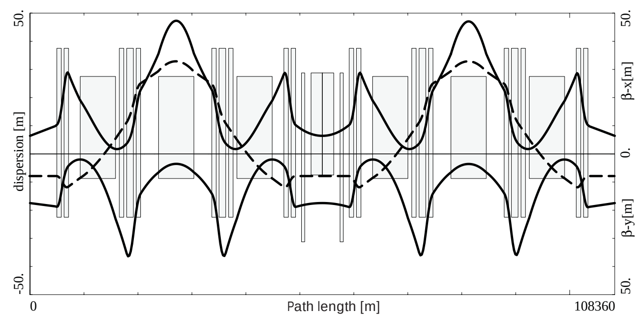

Figure 1: ESR operation mode with low transition energy. Dispersion (dashed line) and betatron functions (solid lines) are given. The lattice structure is sketched for orientation purpose.

account (see [5]). In particular the matching of the betatron phase advance from the injection septum to the kicker limited the number of possible quadrupole settings. The solution we finally found suffers from a negative dispersion in the long straight sections of the ring. This made an even larger dispersion in the central dipoles of both arc sections necessary. At these positions also the horizontal β function is large (see Fig. 1), reducing the possible momentum acceptance further.

2 EXPERIMENTAL

In continuation of former commissioning experiments [5] several ion optical settings with different transition energies were tested. One setting with a transition point of $\gamma_t = 1.37$ was investigated in more detail using ^{12}C and ^{58}Ni primary beams with a matched velocity ($\gamma = 1.37$). This setting is discussed below.

The calculated dispersion function agrees well with measurements at several positions inside the ring, namely in one of the straight sections and around those dipoles where the dispersion function reaches its maxima.

Having in mind the application for mass measurements, where it is crucial to minimize the dependence of the frequency on momentum, our interest is focused on the question to what extend the isochronicity condition $\gamma = \gamma_t$ is fulfilled. Therefore we used the electron cooler [6] in order to produce a beam with a narrow velocity distribution

($\delta v/v = 10^{-6}$) and moved it to different orbits characterized by their momentum deviation $\delta p/p$ relative to a reference orbit.

The result of this measurement with a carbon beam is shown in Fig. 2 and compared with different calculations. The ion optical calculations were carried out using the code MIRKO [7]. Using the quadrupole and sextupole settings applied during the experiment these calculations predicted a linear dependence of γ_t on particle momentum within the momentum range shown. From this linear dependence we derived the frequency as a function of momentum by integrating equation (1). We slightly adjusted the absolute value of γ_t (1.38 instead of 1.39 as calculated for the reference orbit) when comparing this to the measured frequencies (see Fig. 2). The calculation turned out to describe

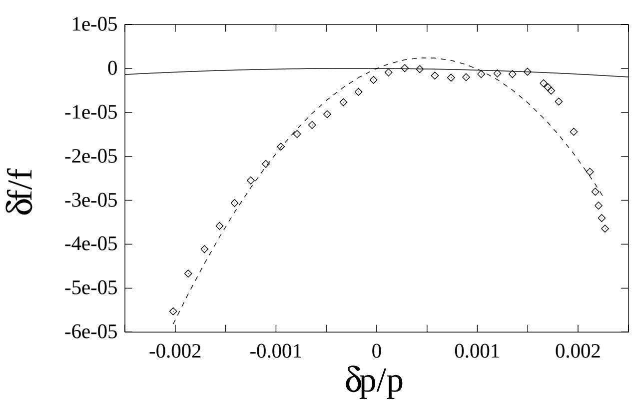

Figure 2: Comparison of measured frequencies (data points) to calculated ones: The dashed line reflects the result from a MIRKO-calculation carried out as described above, using a linear dependence of γ_t on the momentum. The solid curve shows the result calculated with an improved sextupole setting (see 4).

the slope of γ_t as a function of the momentum rather well whereas the absolute values differ by $\approx 1\%$. A similar result was obtained for the tunes, which are not as well reproduced by the calculation as are the chromaticities.

Based on the measurement of the frequency as a function of velocity one can derive the dependence of the path-length C on magnetic rigidity. As this is an inherent property of the setting and therefore does not depend on the mass-to-charge ratio of the ions it allows to predict the behavior of the revolution frequency ($f = v/C$), if the momentum $\delta p/p$ is varied for an ion species different from the one which was used for the measurement. Based on measurements with a ^{58}Ni beam we have calculated the momentum dependence of the revolution frequency for several fragments of ^{58}Ni with roughly the same (i.e. within $\approx 1\%$) mass-to-charge ratio. Taking into account the momentum acceptance of only a few tenth of a percent for this operational mode one can conclude that these ions should be well separated in frequency.

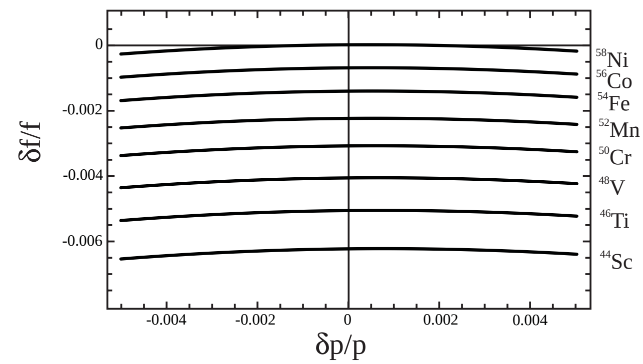

Figure 3: Revolution frequencies for the fragments shown in Fig. 4 as calculated from the measured dependence of the path-length on the magnetic rigidity. The curves correspond to bare ions of (from top to bottom) ^{58}Ni, ^{56}Co, ^{54}Fe, ^{52}Mn, ^{50}Cr, ^{48}V, ^{46}Ti, ^{44}Sc. The measurement was carried out with the primary ^{58}Ni beam. For all fragments $\delta p/p = 0$ refers to a rigidity of 6.01 Tm.

3 MASS MEASUREMENTS OF EXOTIC NUCLEI

As shown in the preceding section the revolution frequency of an ion depends only weakly on its velocity but strongly on its mass-to-charge ratio, if the ESR is operated at transition. Thus for a multi-component beam this mode of operation allows to resolve different species in a frequency spectrum and to derive the mass values from the revolution frequencies.

$$\frac{\Delta(m/q)}{(m/q)} = -\gamma_t^2 \frac{\Delta f}{f} + (\gamma_t^2 - \gamma^2)\frac{\Delta v}{v} \qquad (3)$$

In contrary to the technique of Schottky-Mass-Spectrometry [8, 9], where the $\Delta v/v$-term in equation 3 is minimized by electron cooling which takes several seconds, with the isochronous mode of operation the expression in parentheses is small immediately after injection. This allows to investigate nuclei with lifetimes down to a few times the revolution period, i.e. a few μs.

During the experiments with a nickel beam we injected a fragment beam delivered by the FRS and demonstrated the possibility to resolve different mass-to-charge ratios as is illustrated in Fig. 4.

Due to Fig. 2 the resolution depends on the momentum width of the beam. We reduced the momentum width of the beam prior to injection which allowed us to resolve fragments with a narrow spacing in mass-to-charge ratio, see Fig. 5. From the right peak in Fig. 5 we deduced a mass resolution of $(m/\Delta m)_{\text{FWHM}} = 1.5\cdot 10^5$, which approaches the limit given by the field instabilities.

It is planned to use this operational mode in combination with a detection system [10] that allows to measure the revolution frequency of a single particle within a few turns. This should make feasible a measurement of the masses of short lived nuclei with small production rates, in particular

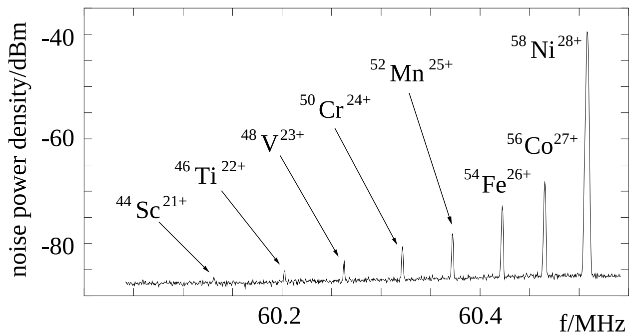

Figure 4: A ^{58}Ni primary beam and fragments with similar magnetic rigidity stored in the ESR during isochronous operation. The relative differences in mass-to-charge ratio between two adjacent peaks in this spectrum is $1\ldots2\cdot10^{-3}$.

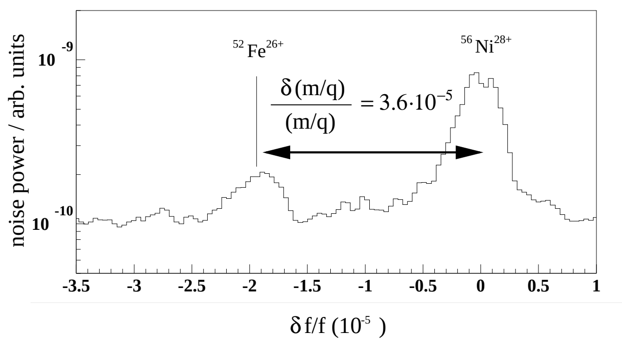

Figure 5: Part of a frequency spectrum recorded in the isochronous mode of operation of the ESR. The two observed species differ in mass-to-charge ratio by only $\approx 3.6\times10^{-5}$.

some exotic nuclei, which are of interest for nuclear astrophysics.

This TOF-detector system has also been put into operation. A trace of the repetitive signal induced by circulating single heavy ions in the ESR is displayed below. For some ions more than 100 turns were observed.

4 SUMMARY AND OUTLOOK

An operational mode of the ESR at a transition point $\gamma_t = 1.37$ has been found. This mode has been investigated experimentally. The results are in reasonable agreement with ion-optical calculations except for the absolute values of some beam-parameters, especially tunes. Differentially the agreement between calculation and experiment is rather good. Multi-component beams produced via projectile fragmentation have been injected and stored during this mode of operation. The resulting frequency spectra are in agreement with calculations.

More recent ion optical calculations have shown the possibility to change the sextupole settings in order to improve the ion optical properties. These slight modifications of the investigated setting should lead to a further weakening of the dependence of γ_t on the momentum. We expect to

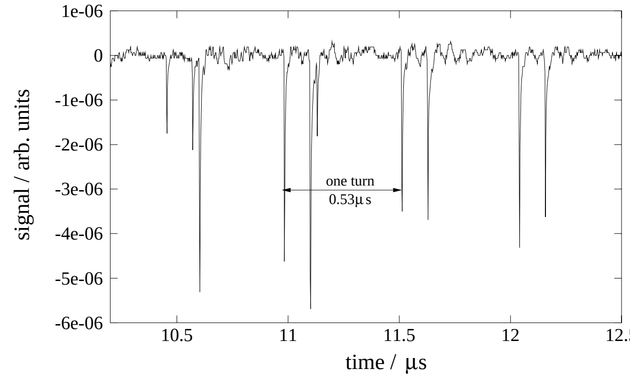

Figure 6: Trace of the analogous detector signal induced by three ions circulating in the ESR. Two of these ions are observed four times while the third one disappears in between. For mass measurements the timing properties of the signal will be improved substantially. We expect to resolve signals of ions separated by only a few ns.

come close to the ideal curve given in Fig. 2 within the limits given by the deviations of the measured data to the smooth calculated curve in Fig. 2.

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REFERENCES

[1] B. Franzke, Nucl. Instr. Meth., **B24/25**, (1987), 18.

[2] K. Blasche, D. Böhne, B. Franzke and H. Prange, IEEE Trans. Nucl. Sci. **Ns-32** (5), (1985), 2657.

[3] H. Geissel *et al.*, Nucl. Instr. Meth. B70, (1992), 286.

[4] H. Wollnik, Nucl. Instr. Meth. **A258**, (1987), 289

[5] A. Dolinskiy *et al.*, in: *Proc. 5th Europ. Part. Accel. Conf., Sitges, 1996*, 596

[6] N. Angert *et al.*, in: *Proc. Europ. Part. Accel. Conf., Rome, 1988*, 1436.

[7] B. Franczak, in: *Computing in Accelerator Design and Operation*, (1984), 170.

[8] B. Franzke *et al.*, Phys. Scr. **T59**, (1995), 176 and B. Schlitt, PhD thesis, University of Heidelberg, Germany.

[9] T. Radon *et al.*, Phys. Rev. Letters **78**, (1997), 4701 and T. Radon, PhD thesis, University of Giessen, Germany and Th. Kerscher, PhD thesis, University of Munich, Germany

[10] J. Trötscher, *et al.*, Nucl. Instr. Meth. **B70**, (1992), 455.