The ESR Schottky-Diagnosis-System

K. Beckert, S. Cocher, B. Franzke, U. Schaaf
GSI - Darmstadt, D-6100 Darmstadt, FRG

1 Introduction

In addition to the determination of a variety of interesting beam parameters, one of the important tasks in the ESR is the observation of possible particle beam instabilities and the measurement of their properties to understand the driving mechanisms and to find means for a cure.
The planned system will allow on-line measurements of normal Schottky spectra (longitudinal and transverse) and of beam transfer functions, yielding information on the revolution frequency and energy of particles, betatron tune and chromaticity, synchrotron frequency and rf-amplitude, emittance and particle distributions and providing also data on the ring itself (stability limits, wall impedance, field error effects, working line). In the case, that transversely unstable modes should occur an active feedback system will be used to damp these oscillations.
Originally, one of the 12 available ESR position monitors (diagonal split type, length 11 cm, band width 100 MHz, coupling impedance 1 $M\Omega$) should have been used for Schottky diagnostics as well, because they were planned to deliver both the analog sum and difference signals. But, based on experiences gained during first Schottky measurements at SIS it has been decided to instal a dedicated pickup in the ESR as soon as possible. This new monitor has a considerable greater length than the position monitors; its coupling impedance will be 50 Ω, and it can be used in the electrostatic mode as well as in the stripline mode. These changes lead to a much higher sensitivity and therefore allow the detection of smaller signals. The design of the monitor has been completed and it will be manufactured during spring 1990.

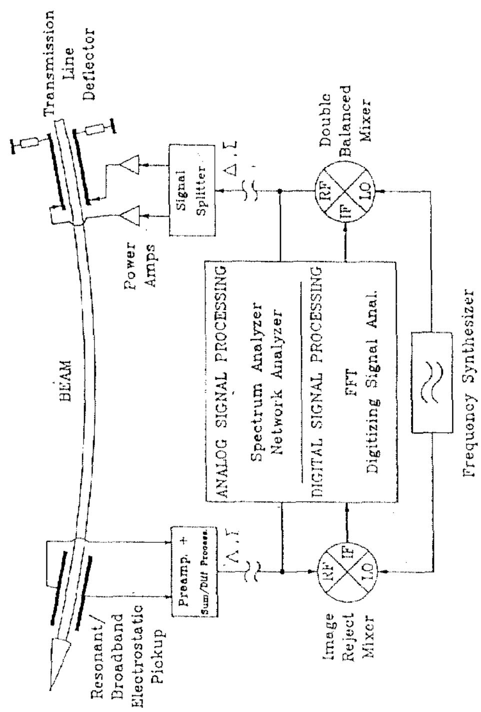

Figure 1: *Equipment for Schottky Diagnostics.*

2 Measurement Setup

To control the electronics at the beam line the possibilities offered by the ESR/SIS control system will be used instead of the formerly planned multiprogrammer unit.

A substantial improvement of the analyzing capacity will be achieved by using the DSA 602, a fast digitizer, which allows the recording of very short transient events with excellent time resolution. The time spectra will then be Fourier transformed and evaluated on a HP9000/340C+ computer equipped with a lot of convenient graphics features. This opens up a completely new group of measurements in addition to the normal spectrum analyzer, the FFT-analyzer and the network-analyzer.
Since it is fairly complicated to satisfy the phase relation in feedback applications for different operation modes by using only one monitor another solution was necessary. A method developed in CERN will be adopted. By applying the signals from two pickups to the kicker, the phase angle of the feedback signal can be varied. The signal levels from the two pickups are individually adjusted with the correct settings obtained from the beam transfer function (BTF). To achieve the large necessary bandwidth, the signal travel time between pickups and kicker has to correspond to the time of flight of the particles.
A diagram of the planned equipment is shown in Fig.1. The above mentioned devices are all available; the necessary software will be written during the next month and years; the required electronics has been developed and ordered.

3 Results

Using a resonant position monitor in a preliminary setup, successful Schottky measurements were possible from beginning on in the SIS/ESR-complex. Measurements have been carried out with different ions ($Ar^{10+}, Xe^{21+}, Kr^{16+}$ and Ne^{10+}) at energies from 10 to 100 MeV/u and bunched as well as coasting beams. By the end of multi-turn injection the beam current reached typically a maximum of some 10 μA. Suitable events from the control system have been used to start the evaluation of a spectrum and then up to 500 spectra of succeeding machine cycles have been averaged to improve the measurement accuracy. In addtion to normal Schottky-scans we analyzed transverse spectra resulting from a short excitation by a magnetic kicker. Figure 2 shows several longitudinal Schottky-bands of succeeding harmonics of the particle revolution frequency. The effect of the resonant pickup is clearly visible. The shape of each harmonic is a direct image of the particle frequency distribution. That allows us to determine the momentum spread of the beam and the distance of the harmonics gives the average revolution frequency and particle energy respectively. Figure 3 shows the splitting into several synchrotron satellites of a single Schottky-band in the case of a bunched beam. The synchrotron frequency can easily be evaluated by measuring the distance of these satellites. In figure 4, the narrowband time domain measurement shows the integral power of a Schottky-band as a function of time. The beam lifetime (e-folding time) is determined by the slope of this curve. The following list finally gives a short review of the results obtained in 1989. With Schottky-scan methods, we have been able to measure

- the exact particle revolution frequency and energy
- the particle frequency distribution and momentum spread of the beam
- the synchrotron frequency in the case of a bunched beam
- the average betatron tune Q and moreover the so called "working line" i.e. the variation of the betatron tune across the particle momentum distribution. The slope of this curve defines the chromaticity ξ.
- the variation of the betatron tune Q and the chromaticity ξ in a wider range (across the aperture) by varying the RF-frequency and evaluating the tune at several points.

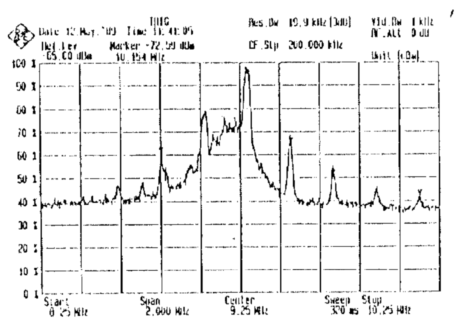

Figure 2: *Longitudinal Schottky-bands of a Xe^{21+} beam (11.6 MeV/u) at several harmonics of the particle revolution frequency. The increase of sensitivity due to the pickup resonance around 9 MHz is clearly visible.*

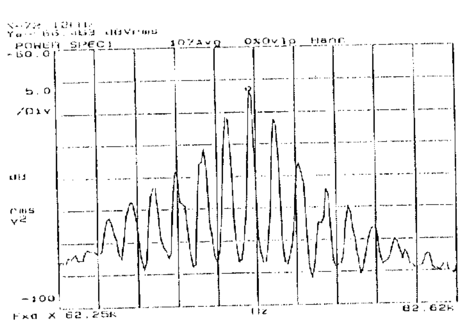

Figure 3: *Longitudinal Schottky-band with same beam parameters as above and RF on (bunched beam). The distance of the synchrotron satellites gives the synchrotron frequency of the particles.*

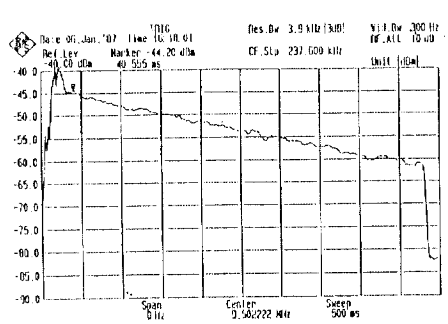

Figure 4: *Narrowband timedomain measurement showing the integral power of a Schottky-band as a function of time. From the slope of this curve a beamlifetime of $\tau = 290$ ms can be evaluated.*

4 Working Line Measurement

The variation of the betatron tune with momentum defines the working line. It can be determined by analyzing the two sidebands of the transverse Schottky spectrum. Hereward [1] proposed a method to find corresponding points in the fast and slow wave band where the signals are induced by the same particles. This method uses the fact that the contribution of each particle to the total signal power is the same in each side band. Therefore, the total signal power below corresponding points is identical in both bands.

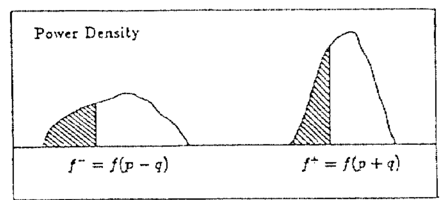

Figure 5: *Corresponding points in slow and fast-wave sidebands.*

Using an appropriate computer program the equivalent points are determined by integrating the signal power from two known corresponding points. The edges of the bands could be used, but they are not well defined in most cases. Therefore, the integration is started at the center of the bands where the integrated signal strength equals half of the total power. The fractional part of the tune and the revolution frequency are then defined by

$$\begin{aligned} q &= p(f^+ - f^-)/(f^+ + f^-) \\ f &= (f^+ + f^-)/(2p) \end{aligned}$$

where p is the harmonic number. This method is usually applied to uncorrelated Schottky spectra. In order to improve the signal to noise ratio, the beam has been kicked by a short pulse. The measured signal comes from the collective beam response to the pulse and is identical to the well-known beam transfer function. Although this signal differs in frequency domain from the Schottky power spectrum, we found that the method proposed by Hereward can also be applied to the power spectrum of a kicked beam.

Results obtained with this method are shown in Fig. 6 . For calculations we used the measured horizontal betatron sidebands of Fig. 7 . They are in good agreement with the results obtained with a complementary method (Fig. 8) which considers the variations of the mean tune of a kicked bunched beam at different RF-frequencies. This method determines the tune with frequency steps larger than the beam frequency spread and doesn't give information about the tune variations within the particle frequency distribution. Nevertheless the chromaticity obtained with these two methods are in good agreement. It is proportionnal to the slope of the tune curves. We found -0.8 with the first method and -1 with the second one.

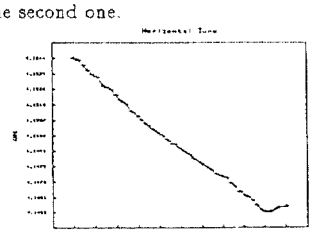

Figure 6: *Horizontal betatron tune distribution vs revolution frequency within the particle frequency distribution.*

5 Particle Momentum Distribution

In the case of negligible coupling impedance, both Schottky- and BTF-scans allow a direct measurement of the particle revolution

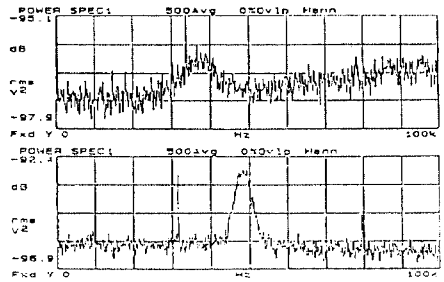

Figure 7: *Fast-wave (a) and slow-wave (b) sideband of a Ar^{10+} coasting beam at 100 MeV/u at the 20th harmonic of the revolution frequency.*

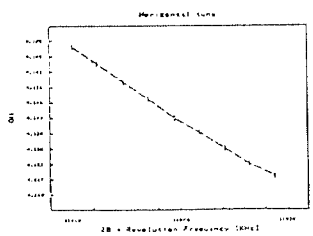

Figure 8: *Mean horizontal betatron tune distribution vs RF-frequency.*

frequency distribution. However, at high phase space density (e.g. for very cold beams) Schottky spectra as well as BTF's are strongly distorted. Nevertheless, there are several alternatives to determine both the particle distribution and the coupling impedance using the measurement techniques mentioned above:

- The real part of the coupling impedance can be found from the horizontal shift of the asymptotes of the measured stability diagram. The particle distribution can then be calculated directly from a longitudinal Schottky spectrum and the real part of the BTF.
- If the asymptotes of the stability diagram should not be clearly defined, a certain test impedance might be used to calculate the particle distribution from the BTF. It will be equal to the distribution determined from the Schottky spectrum if the test impedance coincides with the actual impedance.
- Assuming a symmetric particle revolution frequency distribution, one longitudinal BTF-measurement is sufficient to evaluate roughly the coupling impedance and thus the particle distribution.

6 Electron Cooling in the ESR

On May, 13th, electron cooling was successfully tested in the ESR for the first time. The $^{40}Ar^{18+}$ beam (92 MeV/u), with an initial momentum spread of about $\Delta P/P = 3 \cdot 10^{-3}$ was cooled to a finite momentum spread of $\Delta P/P = 3 \cdot 10^{-5}$. Fig.9 shows the particle frequency distribution of the cooled ESR-beam together with the initial distribution as reference.

Fig.10 is a time domain measurement which allows to determine the cooling rate and to optimize it. The high voltage of the electron cooler is stepped to a higher level. As a consequence, the Schottky-bands move over a certain frequency range. The speed

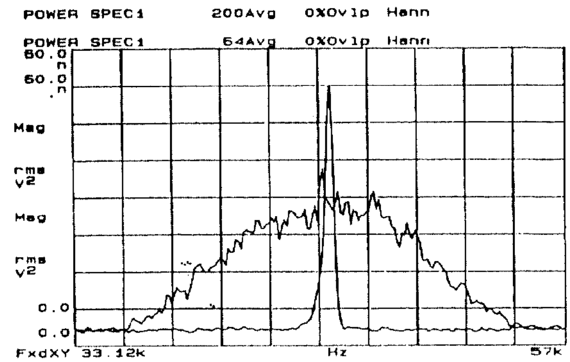

Figure 9: *Distribution of the cooled ESR-beam.*

of this movement is a measure of the cooling rate. It is evaluated by measuring the time it takes the Schottky band to move across three rf-buckets created by an amplitude modulated carrier which is placed somewhere between the initial and the final position of the Schottky band.

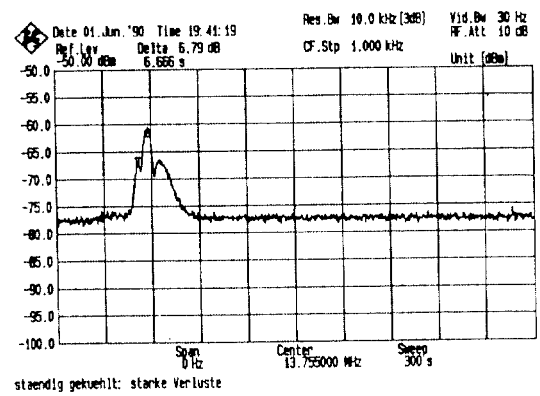

Figure 10: *Time domain measurement.*

A more detailed description of the future plans concerning the diagnostics of cooled ion beams is given elsewhere in this volume [2].

References

[1] S. van de Meer, *Diagnostic with Schottky Noise*, presented at the US-CERN School, October 1988, Capri, Italy.

[2] I.Hofmann, S.Baumann, K.Beckert and U.Schaaf, *Diagnostics and Instability Studies of Cooled Ion beams*, this Volume.