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STATUS OF BESSY, AN 800-MeV STORAGE RING DEDICATED TO SYNCHROTRON RADIATION

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I. Introduction

BESSY [1,2] is a national dedicated source for synchrotron radiation situated in Berlin (West). This facility includes a 800 MeV electron storage ring, a 800 MeV separated function injector-synchrotron and a 20 MeV preinjector-microtron. The storage ring is available for the following three classes of user groups:

i) Basic and applied research performed by universities and research institutions.
ii) Industrial development in the field of X-ray lithography.
iii) Radiometry.

The critical wavelength of BESSY was chosen to be λ_c = 2 nm. This corresponds to a maximum field strength of 1.5 T in the bending magnets at 800 MeV and a bending radius of 1.78 m. By this choice of the spectral range BESSY meets the demands of X-ray lithography and complements the hard X-ray laboratory HASYLAB at DESY (Hamburg). Together with the HASYLAB facility both laboratories are thought as national centers for research with synchrotron radiation. BESSY covers the spectral range in the infrared, VUV and soft X-ray region up to 5 KeV photon energies. In order to meet the demands of the users in the different fields, a magnet lattice has been chosen, which allows operation of the storage ring with different magnet optics. This flexibility could be achieved with eight quadrupoles and three 30° bending magnets per lattice cell. The lattice has a four fold supersymmetry (fig.1).

II. Operational status

In December 1981 the first beam of several µA has been stored. After half a year of exclusive machine development user operation started in July 1982. In the second half of 1982 about 480 h of beam time have been at the user's disposal. For 1983 60% of total machine time will be given to the users, 20% are planned for machine development and 20% for maintenance. At the moment the storage ring is operated about 12 hours per day. During the night the machines are put in a standby mode. Normal machine operation starts at 9 o'clock in the morning and finishes at 9 o'clock in the evening. Daily operation over 16 hours in 2 shifts will be established in this year.

In basic research nine monochromators have been commissioned and given over for user operation at the moment. Six more monochromators are currently being constructed or in an advanced state of planning. Some forty user groups from universities, the Max-Planck-Society and other research institutes will work on the fifteen BESSY-monochromators (or bring their own monochromators) for a range of experiments in solid state, surface, atomic and molecular physics as well as in photochemistry and biology.

Of the available six beam lines in the lithography laboratory two were commissioned in September 1982 and fitted with exposure chambers. Two more lines equipped with "X-ray steppers" will go on line later in 1983. Experiments are being performed here by the Fraunhofer-Society together with four German semiconductor companies.

The radiometry laboratory of the Physikalisch-Technische Bundesanstalt (german equivalent of NBS) also started operation in the autumn of 1982. Currently two beam lines are in operation.

III. Machine operation

So far the machine successfully has been operated in two different optics. Tab. 1 and fig. 2 show the main parameters and amplitude functions. The optics called XRAY is mainly intended for X-ray lithography and experiments demanding a high photon flux. Its large emittance and beam dimension should provide sufficient transverse Landau-damping to allow the accumulation of high currents. Theoretically this optics yields a Touschek-lifetime of 20 h at the maximum design current of 500 mA. The focussing strengths of this optics are less than 25% of their maximum value, corresponding to a field gradient of 12 T/m. The natural chromaticities are small and can easily be compensated. Therefore, due to its conventional parameters, this optics has been used for initial operation of the storage ring, and during the last year. The following experiences have been obtained with this optics:

i) Normal vacuum conditions in the ring are $<10^{-9}$ mbar without beam and $< 10^{-8}$ mbar with a beam of 200 mA. Under these conditions lifetimes of 120 min at 200 mA and 200 min at 100 mA have been achieved.
ii) Typical injection rates are 120-150 mA/min. The injection efficiency is estimated to be 50%. The injector-synchrotron with a 10 Hz repetition rate, delivers presently a peak current of about 5 mA per 50 ns burst [3]. Until now the experiments do not need higher currents than 200 mA in the average. Three injections of typically five minutes duration each are presently sufficient for a daily machine operation of 10 hours.
iii) An upper current limit of 320 mA has been found, caused by a yet not completely identified instability. A pair of horizontal capacitive plates, which is fed by a rf-signal, is used for stabilisation of the beam. To get effective stabilisation, the frequency of the signal is tuned slightly below the horizontal betatron resonance. Without this excitation the current limit drops below 150 mA.
iv) If the beam reaches the current limit, mainly sidebands due to horizontal betatron oscillations and strong sidebands due to synchrotron-oscillations are visible in the frequency spectrum of the beam. One sideband of the third harmonic of the revolution frequency at 1585 MHz could be identified as a parasitic cavity mode. The excitation of this mode is dependent on the longitudinal working point. It seems that the narrow band impedance of the cavity excites a longitudinal coupled bunch oscillation mode in the beam.
v) A vertical blow-up of the beam at the current limit can be seen on the synchrotron radiation monitors. Due to the lack of vertical betatron sidebands in the frequency spectrum, this blow up is caused by incoherent oscillations.
vi) The influence of ionized residual gas atoms on the beam is clearly visible. Fig. 3 shows the Q-shift at a pressure of 5×10^{-8} mbar. At increasing current the vertical working point is shifted to a half resonance.
vii) A current dependent bunch lengthening has been observed with a streak camera. The extrapolation to small currents fits well with the theoretical bunch length (fig. 4).

Last month the optic METRO successfully has been put into operation. METRO is optimized for maximum spectral brilliance*. This optics is intended for radiometry and high resolution experiments. It has a very small horizontal emittance, which is about 50 times smaller than the emittance of XRAY. The brilliance of this optics is expected to be ~400 times larger and the momentum compaction factor is 100 times smaller than for XRAY. The small bunch volume strongly reduces transverse Landau-damping and Touschek-lifetime. Therefore maximum currents not larger than 200 mA are expected. Up to now a current of 130 mA with a lifetime of ~70 min could be accumulated. The injection rate was typically 30 mA/min. The measured chromaticities of the uncompensated machine with this optics are ξ_H = -10.0 and ξ_V = -6.7, the energy acceptance is 0.8%. Fig. 5 shows measured beam sizes in the transverse planes as a function of stored current. The strong increase in vertical beam size indicates a current dependent coupling mechanism from the horizontal to the vertical plane. At low currents the measured beam sizes are about a factor of 2.5 larger than predicted by theory.

IV. Future plans

1) At the end of this year a second rf-system operating at 62.5 MHz (harmonic number h = 13) will be installed in the storage ring. The rf-output power of this system will be 20 KW. Two interesting operation modes will be available with this system:

i) Using the 500 MHz (h = 104) rf-system for potential deformation of the 62.5 MHz bucket, the charge density in the bunch can be decreased due to bunch lengthening. In addition, the different synchrotron oscillation frequencies along the bunch give rise to longitudinal Landau-damping.

ii) To fight against longitudinal coupled bunch instabilities, the 62.5 MHz system can be operated as a subharmonic system to decouple the synchrotron frequencies of eight successive bunches.

The cavity of the 62.5 MHz system is under construction. It will be a capacitively loaded coaxial $\lambda/2$-resonator with a theoretical shunt impedance of 2.5 MΩ and a quality-factor Q_o = 16000.

2) It is planned to operate the storage ring in the single bunch mode for experiments performing time resolved spectroscopy. This mode will lead to a bunch distance of 208 nsec. The most economic approach is to produce a single electron bunch in the injector-synchrotron (7.8 MHz rf-system) and to inject this bunch into a 62.5 MHz bucket of the storage ring. This bucket can then be compressed by switching on the 500 MHz rf-system.

3) A technical study for the construction of a multipole wiggler has been made[4]. This study proposes a multipole structure with a period of λ_o = 7 cm and N=36 periods. The maximum field strength will be 1.1 T on the beam axis. By changing the gap height from 7.4 to 1.5 cm, this structure works as an undulator (K ~ 0.5) as well as a wiggler (K ~ 7.3). The time schedule for this project foresees a final design study at the end of 1983 and first operation at the end of 1984.

References

1) D. Einfeld, W.-D. Klotz, G. Mülhaupt, T. Müller and R. Richter; IEEE NS 26 (1979) 3801
2) D. Einfeld and G. Mülhaupt; Nucl. Instr. & Meth. 172 (1980) 55
3) this conference
4) W. Gudat and E. Umbach, BESSY TB 39/1983

* defined as number of photons/unit time/unit area of the source/unit solid angle/0.1% band width.

	XRAY theor.	XRAY exp.	METRO theor.	METRO exp.
horizontal emittance ε_H |π x rad x m|	2×10^{-6}		3×10^{-8}	
working point				
ν_H	2.83	2.78	5.80	5.63
ν_V	1.47	1.47	2.20	2.16
momentum compaction				
α	0.12		0.0014	
chromaticity				
ξ_H	-2.77		-12.81	-10.0
ξ_V	-0.04		- 5.9	- 6.7
beam size* |mm|				
σ_H	2.9		0.08	0.20
σ_V	0.9		0.08	0.10
beam divergence* |mrad|				
σ'_H	0.37		0.33	
σ'_V	0.17		0.033	
coupling				
κ |%|	10**	30	10**	up to 100
max. amp. function |m|				
β_H^{max}	8.0		11.0	
β_V^{max}	15.5		18.5	
max. dispersion |m|				
η_H^{max}	1.17		0.85	
max. current |mA|				
I_{max}		320		140
life time for 100 mA				
τ_{100} |min|		200		70
injection rate				
$\dot{I}$ |mA/min|		130		30
max. closed orbit distortion |mm|				
horizontal		6		2
vertical		8		7

*) in first bending magnet, **) estimated value

Table 1

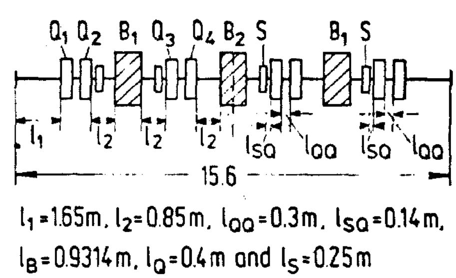

Fig.1: Magnet lattice cell, B = bending magnet, Q = Quadrupole, S = Sextupole

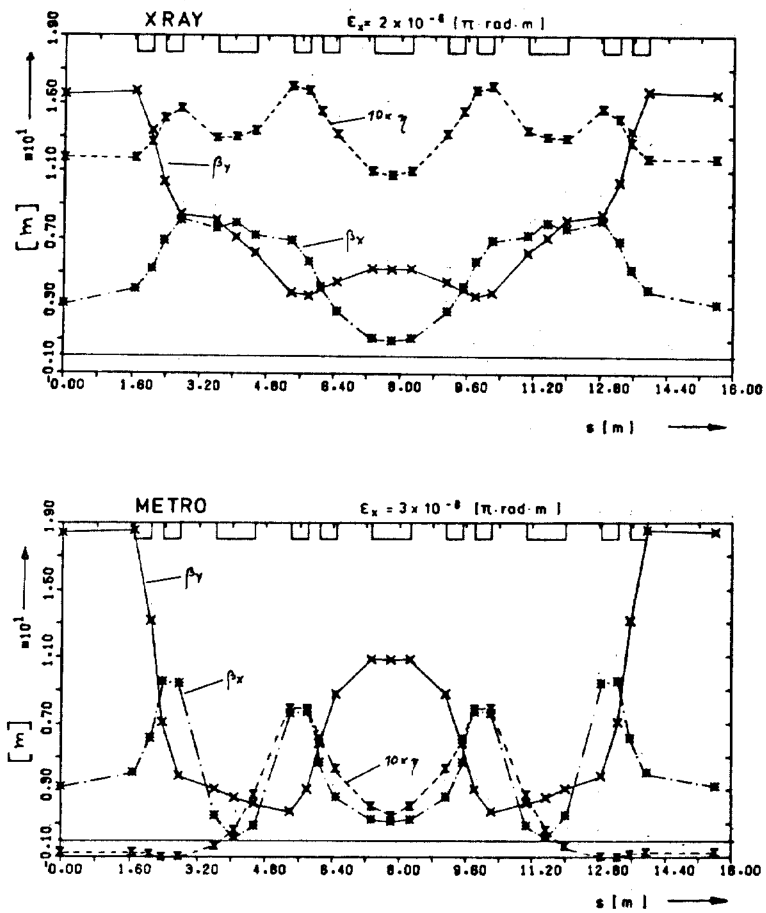

Fig.2: Amplitude functions for two BESSY-optics

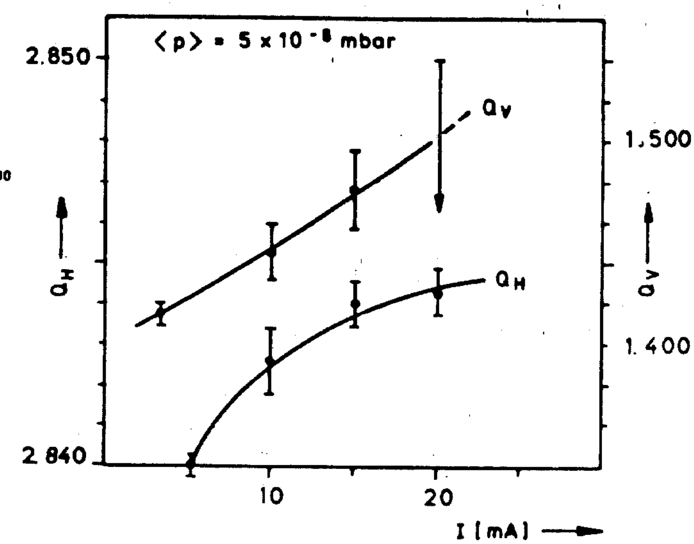

Fig.3: Working point for optics XRAY as a function of stored current

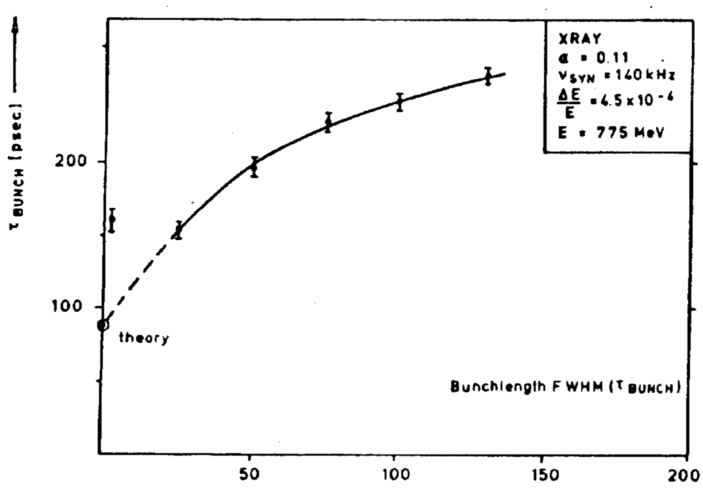

Fig.4: Bunch length as a function of stored current

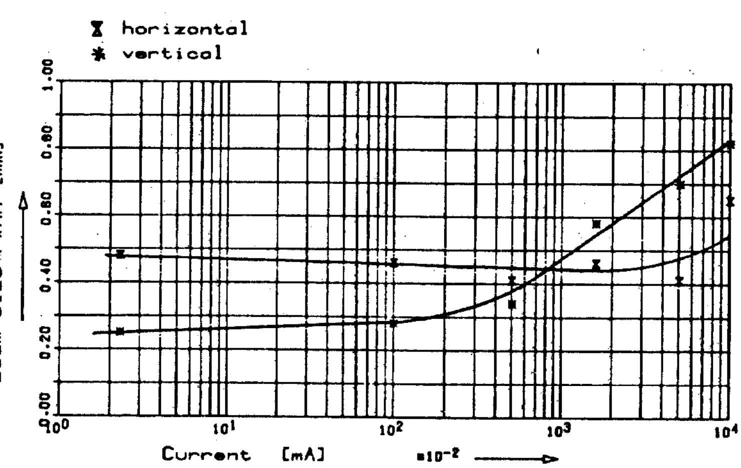

Fig.5: Transverse beam sizes for optics METRO as a function of stored current