FIRST EXPERIENCE WITHTHE SUPERCONDUCTING ASYMMETRIC WIGGLER OF THE DELTA FACILITY

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Abstract

The superconducting asymmetric wiggler (**SAW**) is a unique insertion device operated at the DELTA facility. This multipole wiggler magnet with 21 poles provides the possibility of both symmetric operation up to 2.8 T and asymmetric operation up to 5.3 T, featuring the possibility to produce circular polarized photons of about 8 keV in a 1.5 GeV storage ring. This paper will give a detailed description of the device itself, and will further describe the first results of the operation of this wiggler in the storage ring.

1 CHARACTERISTICS OF THE SAW

To satisfy the present need for the generation of intense, circular polarized synchrotron radiation in the x-ray part of the spectrum, a superconducting 5.3 Tesla asymmetric multipole wiggler with a semi-cold vacuum chamber was designed at DELTA [1,2,3] and manufactured by the German company ACCEL [4]. A special coil arrangement consisting of NbTi-wires allows two operation modes:

- symmetrical with a sine-like field of 10 periods with a peak field of 2.8 Tesla.
- asymmetrical with 5 periods and a peak value of 5.3 Tesla.

The critical photon energy is about 4.1 keV for the symmetrical mode and 7.9 keV for the asymmetrical mode.

The order for the wiggler has been placed in February 1995. First field investigations took place in October 1997 at ACCEL. Both required peak fields have been reached. Results were obtained by the pulsed wire method, which has been used successfully at DELTA during the field measurement of the FEL undulator [5].

The first field integral is determined using a short rectangular pulse, the corresponding magnetic field being proportional to the derived signal. To get an exact measurement of the field integral at the end of the wiggler, a periodical rectangular pulse (t=1.3 ms for the asym. case and t=0.65 ms for the sym. mode) has been used. A step-pulse has been applied to obtain the second field integral. Both field integrals were trimmed to zero accurately, to avoid an effect on the electron trajectory at the end of the wiggler and to cancel out a (horizontal) shift of the ideal closed orbit.

The following table 1 summarizes the most characteristic features of the SAW.

Table 1: Main Wiggler Parameters

Wiggler Parameter	
Max. magnetic field	2.79 T sym. mode 5.30 T asym. mode
Period length	14.4 cm sym. mode 28.8 cm asym. mode
Number of periods	10 sym. mode 5 asym. mode
k-values	36 sym. mode 149 asym. mode
Number of coils	19 inner-, 5 outer-, 2 edge-coils
Maximum pole length	170 mm
Maximum pole width	30 mm
No. of turns per coil (inner / outer section)	64×12 / 64×18
Wire material / Insulation material	monolithical NbTi super-conductor / copper
Copper / NbTi ratio	1 : 3
Wire diameter (incl. insulation)	0.7 mm
Wire length (inner / outer section)	280 m / 480 m
Max. current density	395 A/mm^2
Critical current @ 5 T & 4.2 K	471 A
Max. magnetic field @ wire (asym. mode)	7.3 T (asym. mode)
Max. stored energy	94 kJ (asym. mode)
Magnetic length	1.44 m
Total length	2.50 m
Pole gap	18 mm
Vacuum chamber width	90 – 120 mm (beam entry – beam exit)
Vacuum gap	10 mm
Chamber type	Semi-cold
Chamber temperature	< 20 K
Helium capacity / working volume	297 l / 173 l
Helium consumption	0.3 l/h liquid He = 201 l/h gaseous He = 194 mW
Max. pressure inside cryostat	1.1 bar abs.
Total weight (without Helium)	2250 kg

2 WIGGLER COMMISSIONING

2.1 Commissioning of the wiggler device

The superconducting multipole wiggler has been delivered in January 1998. It was commissioned outside the radiation protection shielding of the DELTA facility. The wiggler fulfilled all specifications in the scope of the design parameters. Its behaviour in the case of a quench, that means the response of the quench protection system, has been tested and fulfilled the technical specifications. The exhaust steam rate amounted to 201 l/h gaseous helium, corresponding 194 mW. Liquid helium has to be refilled at least after 1 - 2 weeks under running conditions. The evaporated helium gas is confined and liquified again with a refrigerator at the department of physics at the University of Dortmund. Current feeds are cooled with evaporated helium gas which is reliquified by a 2-stage cold compressor, in order to suppress heat intrusion coming from the current feeds, especially when the wiggler is excited. After some additional vacuum conditioning as well as interlock and control system checks, the device was ready for final installation in the storage ring during the summer shutdown 1999.

2.2 Commissioning of the wiggler optics

Before placing the SAW, some quadrupoles had to be shifted. Two quadrupole families have been installed in the southern straight section of the storage ring. Together with seven additional quadrupole power supplies, one has the flexibility of new optics being concerned with the wiggler (see fig. 1). The wiggler itself has a strong influence on the optics, mainly vertically focussing. Moreover, due to its small vacuum chamber (10 mm full gap), there are vertical aperture limits to fulfill (i.e. a small vertical beta function).

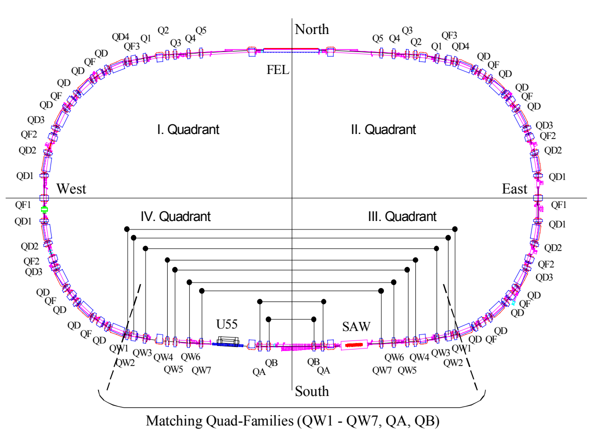

Figure 1: Lattice of the storage ring DELTA with 9 independend quadrupole families in the southern part of the facility.

Therefore, several optic versions of different wiggler magnetic field configurations have been calculated in the framework of a diploma thesis [6]. Within the scope of this work, the edge focussing effect and the effects of the wiggler on electron dynamics have been examined. The dynamic aperture simulations show a sufficient safety margin with regard to beam lifetime reduction. Although these specially designed optics with a kind of mini beta focussing at the wiggler location was available, there might arose some problems with the narrow part of the wiggler gap during injection from the booster. Therefore, the vertical aperture limitation has been simulated before insertion of the wiggler device by the use of vertical scrapers [7]. Fig. 2 shows the injection efficiencies in dependence of the scraper intrusions. The injection and accumulation into the optics setup with the configuration "wiggler off" was possible with a vertical aperture limitation up to 7 mm. With $\beta_{wiggler} = \beta_{scraper} \times (gap_{wiggler} / gap_{scraper})^2$ and $\beta_{scraper} = 3$ m, $gap_{wiggler} = 10$ mm, $gap_{scraper} = 7$ mm, this corresponds to a maximum vertical beta function of 6 m at the wiggler location which is met by the designed optics (see fig. 4). Furthermore, the plot in fig. 2 shows that good steering along the wiggler chamber is required to optimize the injection rate.

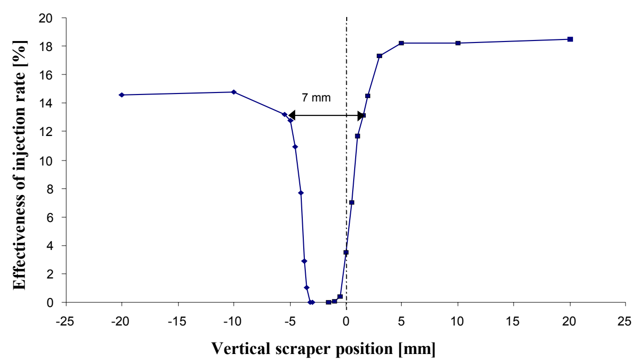

Figure 2: Injection efficiencies versus vertical aperture limitation.

2.3 First wiggler operation

In March 2000, the wiggler has been tested under regular operation conditions for the first time. It turned out, that the quadrupole setting for the unexcited wiggler were sufficent for the excited wiggler as well. The tunes shifted from Qx=9.153, Qz=3.272 to Qx=9.161, Qz=3.295. Injection and accumulation showed no problems. This led to the decision to use the same quadrupole settings for excited and unexcited wiggler.

A serious problem turned out during the commissioning of the wiggler magnet. The superconducting coil windings are connected via solded taps, with a marginal contribution to the ohmic resistance. Because of the high number of taps, this leads to finite current losses in the superconducting circuits. Due to the different number of taps for each of the three current circuits, the trimming of the field integrals is not constant as a function of time, yielding in an time dependend orbit drift. A drift of 1 mm per hour has been observed in the northern part of the storage ring. This can be compensated by a steerer magnet directly upstream of the wiggler device. The attempt to refresh the currents failed due to insufficient accuracy of the wiggler power supplies. To improve orbit stability, we will have to install a slow orbit feedback system.

2.4 Optics measurements

The established wiggler optics has been surveyed at all quadrupole locations using the tune scan method. Since this method requires a linear state of the machine, sextupoles were kept off during the survey. Furthermore, the energy of the storage ring has been scaled down from 1.496 to 0.960 GeV, keeping both Q values constant, to ensure desaturation of all quadrupole yokes for a predictable linear dependence between the strength and exciting current of a quadrupole. For better comparison with theoretical predictions, measured values for the local beta function have been converted to functional values in the center of the corresponding quadrupoles, as done previously in [8]. Doing five measurements at each quadrupole on three different runs, we have a hold on statistical errors at each point as well as a test of reproducibility.

2.4.1 Results

Statistical errors of the surveyed beta functions are typically on the scale of a few percent, except for the extreme values in the beta function present in the northern straight section of the DELTA storage ring, where statistical errors are as high as 10-20 percent. Comparison of different runs of surveys show a rather good reproducibility, typically within 10-15 percent. Shifts of Q-values due to hysteresis of quadrupole yokes have been recorded to vary within +/- 0.1.

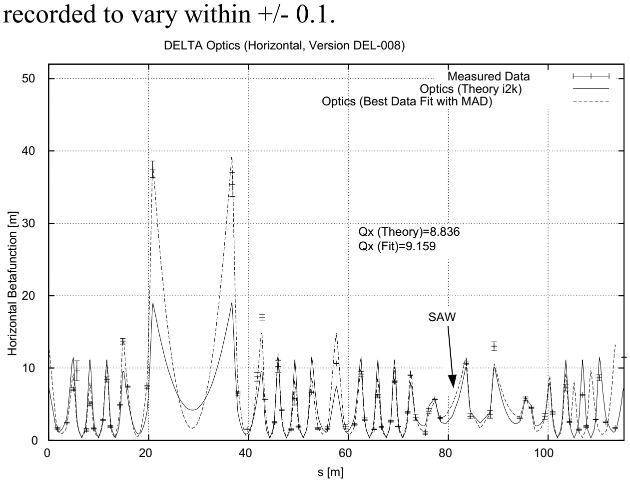

Figure 3: Horizontal beta function of the wiggler optics for the 5.3 T asym. mode. The center of the SAW is located in the range of the mini-beta section at s=82 m.

Best fits of the optical functions have been constructed using the MAD package [9]. To do so, measured points have been entered as constraints to the least square fit with a weight function of the order of one while applying a weight of 1000 to the observed Q-value to ensure reproduction of this well known parameter. Fits have been obtained by varying any of the thirty quadrupole power supplies installed at DELTA within two percent. Representative results for the measured horizontal and the vertical beta functions and their fits are shown in figures 3 and 4 together with theoretical predictions as obtained by the evaluation of set quadrupole currents.

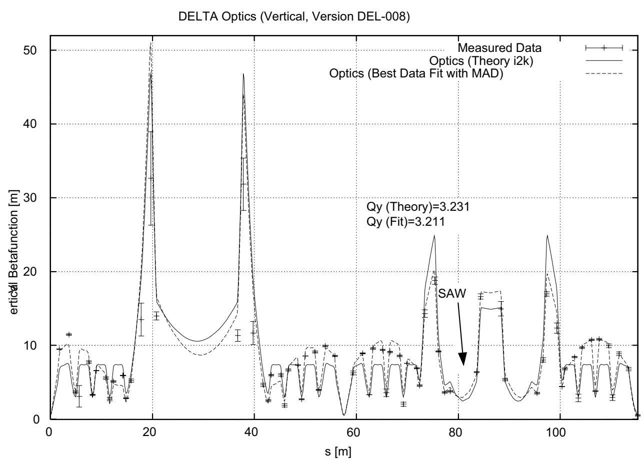

Figure 4: Vertical beta function as in Fig. 3.

Overall, the survey meets the theoretical predictions rather well despite a mismatch in Q-values. While the number of betatron oscillations in the vertical plane agree within the accuracy of the measurement, values for the horizontal plane diverge by an absolute value of 0.32, being separated by an integral number. This discrepancy is not fully understood by now.

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