

DBE_01

Design of Vacuum Chambers and Safety Aspects of a 56 kW Multipole Wiggler

Berger D. Daum R. Krauser H.D. Rose M.

Hahn-Meitner-Institute, Glienicker Straße 100, 14109 Berlin, Germany

Dürr V. Franksen B. Kuner B. Kuszynski J. Rahn J. Wehreter E.

BESSY, Albert-Einstein-Straße 15, 12489 Berlin, Germany

Dirk Berger for the HMI Multipole Wiggler group

Be aware of the heavy heat load of high power superconducting Undulators and Wigglers!

Most of the photon power of a high power insertion device does not reach the beamline but hits the vacuum chamber (fig. 1) and special absorbers (fig. 2). Careful FEM calculations (fig. 2) and a careful chamber design and efficient water cooling (fig. 3) are necessary to guarantee successful and long term operation of such a system. Moreover an accurate and automatic control of the cooling water flow and temperatures as well as a beam position control are required. In case of a failure the electron beam is to be damped by an interlock scheme (fig. 4) immediately.

This talk will show solutions for these tasks based on the experiences with the 56 kW Multipole wiggler installed at BESSY II.

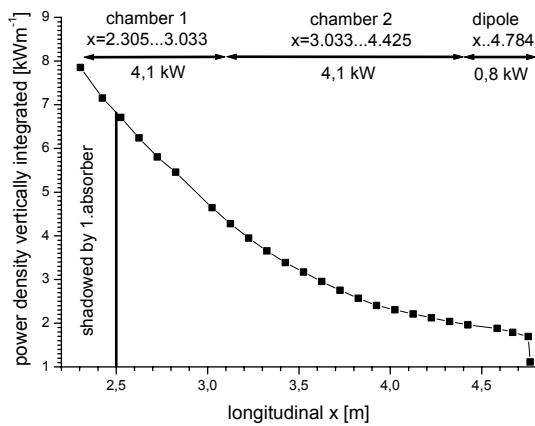


Fig. 1: Heat Load on Inner Vacuum Chamber

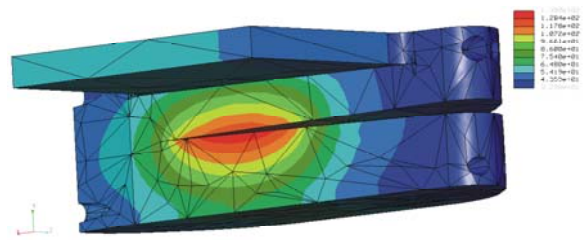


Fig. 2: Temperature Distribution in Two-Wedge-Absorber

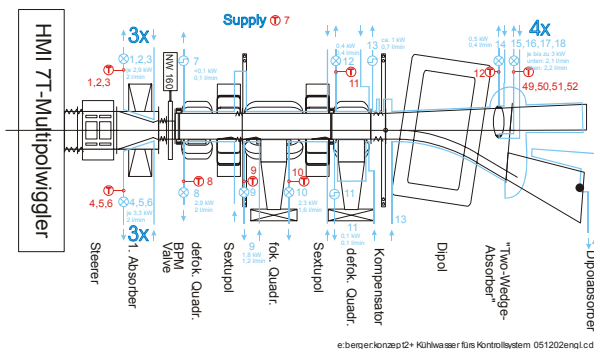


Fig. 3: Water Cooling Circuits

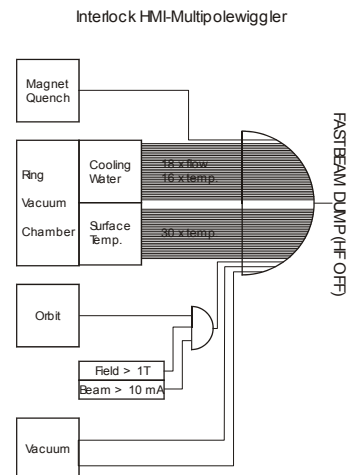


Fig. 4: Interlock Scheme

JCH_01

Impact of in-vacuum permanent magnet undulators on beam dynamics at ESRF

J.Chavanne, M. Hahn, R. Kersevan, C.Penel, B.Plan, F.Revol
ESRF, F38043, Grenoble France

Five in-vacuum undulators are presently in routine operation at ESRF with minimum gap of 5 mm to 6 mm. Their interaction with the stored beam (closed orbit distortions, beam lifetime, tune shift, measured according to a regular basis.) is presented. Resulting from the positive experience with these first five devices, additional in-vacuum undulators are under construction or being planed.

SHKI_01

Status of a Short-Period Superconducting Undulator at APS*

S.H. Kim
Advanced Photon Source, Argonne National Laboratory

A planar superconducting undulator (SCU) with a period of 15 mm is under development at the Advanced Photon Source (APS). The intended user requires radiation that can be tuned from 19 to 28 keV for inelastic x-ray scattering studies. The SCU design consists of two low-carbon-steel cores that are assembled above and below the beam chamber. For a pole gap of 8 mm, the average current density in the coil must be over 1 kA/mm² to achieve a peak field of 0.8T on the beam axis. The present status of a short-section prototype SCU development will be discussed.

* Work supported by the U.S. Department of Energy, Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

SHKI_02

Magnetic Field Analysis of Superconducting Undulators and Scaling Law*

S.H. Kim
Advanced Photon Source, Argonne National Laboratory

The magnetic fields of superconducting undulators (SCUs) of 2-D planar geometries are analyzed, and a scaling law is deduced for the peak fields in the midplane of SCUs and the maximum fields in the coils. By normalizing coil cross section, the peak field is expressed as a function of normalized current density and gap/period ratio. Furthermore, the distributions of the magnetic field and permeability remain unchanged after the normalization. The scaling law is understood from the magnetic field derivation for “air-pole” undulators with a steel yoke. By limiting the normalized current density from a selected critical current, the choice of coil dimensions to achieve the highest possible peak fields will also be discussed.

* Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

SKU_01

Superconducting minigap undulators : engineering & design aspects, parameter range & spectral performances

S. Kubsky

ACCEL

ACCEL is building two superconducting undulator devices both of them with a period length of 14mm, aiming for $B_{max} = 1,4T$ at 5mm gap size, but different vacuum requirements. Based on some successful prototype work, the designs have been developed further and fabrication of cold masses is underway. The respective design and construction concepts will be sketched addressing the most relevant technical questions, i.e. field-simulations, cryogenics, heat load, phase-errors, field-measurement. The status of the first two sc-undulators will be given. The work on several design options led to a "map" of achievable parameters (magnetic field, gap, period length) when applying advanced but conservative rules of engineering. The resulting spectral performance will be shown for several sets of parameters.

RKU_01

APS Plans for Superconducting Undulators*

R. L. Kustom

*Advanced Photon Source, Argonne National Laboratory
9700 South Cass Avenue, Argonne, IL 60439 USA*

Several Advanced Photon Source (APS) users are pressing for higher brilliance at x-ray energies higher than what is reachable in the first harmonic with standard permanent magnet undulators. A program to develop superconducting undulators (SCUs) has begun. The first device will be designed to cover the 20- to 27-keV range in the first harmonic. It will have a 15-mm period, 7-mm beam aperture, and 0.8-T peak field. Longer-range plans are to develop magnetic field measurement and tuning techniques so future SCUs will be able to deliver high brilliance at higher harmonics, and to strive for shorter 12-mm undulator periods. The program activities and proposed schedule will be presented. A short discussion of work on beam-related heat loads and thermohydraulic calculations will be presented.

* Work supported by U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

NME_01

Superconducting High field magnets for storage ring generation in Budker INP

S.V.Khruschev, G.N.Kulipanov M.V.Kuzin, V.Kh.Lev, N.A.Mezentsev, E.G.Miginsky, V.A.Shkaruba, V.M.Syrovatin, V.M.Tsukanov, V.K.Zhurba, K.V.Zolotarev
Budker Institute of Nuclear Physics, SB RAS, Lavrentiev ave.11, 630090 Novosibirsk, Russia

Several high-field superconducting wigglers (SCW) and wavelength shifters (WLS) have been fabricated in Budker INP for generation of synchrotron radiation. Among of them three-pole WLSs with the magnetic field of 7 T were installed on LSU-CAMD and BESSY-II storage rings for generation of harder X-rays. WLS with the field of 10 T was installed and commissioned on

Spring-8 storage ring for generation of photons on MeV range. Two superconducting multipole wigglers were fabricated and commissioned: 7 T, 17 pole wiggler for BESSY-2 storage ring and 3.5 T, 49 pole for ELETTRA storage ring.

Magnet system of 9 T superbend for BESSY-2 was successfully tested in bath cryostat and maximum field of 9.38 T was achieved.

The main characteristics, design features and synchrotron radiation properties of these devices are presented in this article.

BPO_01

Impact of Mini-Gap Undulators on Beam Dynamics and Operations at NSLS

B. Podobedov for the NSLS team

NSLS

The NSLS has been developing in-vacuum mini-gap undulators (MGUs) for well over a decade [1], and, at 3.3 mm, still holds the record for the smallest ID gap of any operating facility. Presently the NSLS X-ray ring has two MGU devices installed at beamlines X13 and X29, respectively; the installation of a 3rd MGU (possibly superconducting) at X9 is planned in the future. So far the impact of the MGUs on the machine has been small and predictable: twice a day the gap has to be opened to 10 mm for injection; after ramping to the operating energy of 2.8 GeV, closing the gap to 3.3 mm reduces the beam lifetime by <10 %. Recent installation of the X29 MGU seems to have slightly increased the tune shift with current, however no collective effect limitations are observed so far. Single bunch currents of up to 125 mA are still possible, with the (administrative) limit set due to heat in vacuum chamber components unrelated to MGUs.

The NSLS is vigorously pursuing the design of NSLS-II – a new ultra-low emittance 3 GeV 3rd generation storage ring with a top-off injector to eventually replace the existing facility [2]. To achieve the 1000-fold increase in undulator brightness NSLS-II will rely heavily on superconducting MGUs. Unlike the present X-ray ring, the MGUs will have a major impact on NSLS-II, affecting the beam dynamics and the overall design of the machine. A first look at beam dynamics reveals the need for further studies of collective effects due to MGUs, as well as optimization of transitions to the mini-gap chamber.

BPO_02

Image Current Heating in Cold Bore Superconducting IDs

B. Podobedov

NSLS

The NSLS is vigorously pursuing the design of NSLS-II – a new ultra-low emittance 3 GeV 3rd generation storage ring with a top-off injector to eventually replace the existing facility [1]. To achieve the 1000-fold increase in undulator brightness NSLS-II will rely heavily on superconducting MGUs. The present MGU design includes 5 mm full gap inner chamber cooled to liquid He temperature. The amount of heat deposited by the beam image current into this chamber is very important to estimate the feasibility of the cryogenic design.

For the few mm bunch-length of interest, the copper is going to be in the extreme anomalous skin effect regime, and therefore the usual resistive wall impedance formulas do not apply. It is possible, however, to calculate the heat deposition (as well as other impedance-related quantities) based on the well-known expressions for surface resistance in the extreme anomalous skin effect regime [2], at least when the bunch length is not too short. In this talk I will give the heat load estimates for the NSLS-II. I will also discuss the applicability limits of the present treatment as well as possible “correction factors” due to transition effects at the ends of the device, surface roughness, magneto-resistance, etc. Finally, I will present some calculations applicable to linac-based machines with very short bunches where the image current generated heat (for CW linacs) and/or energy spread could be of interest as well.

[1] NSLS UPGRADE CONCEPT

B. Podobedov, J. Ablett, L. Berman, R. Biscardi, G.L. Carr, B. Casey, S. Dierker, A. Doyuran, R. Heese, S. Hulbert, E. Johnson, C.C. Kao, S.L. Kramer, H. Loos, J.B. Murphy, R. Pindak, S. Pjerov, J. Rose, T. Shaftan, B. Sheehy, P. Siddons, N. Towne, J.M. Wang, X.J. Wang, L.H. Yu,
Proceedings PAC03, 2003

[2] Landau & Lifshits, Physical Kinetics. The original derivation was given by Reuter and Sondheimer, Proc Roy. Soc. (London) A195, 336, 1948.

SPR_01

Superconducting Undulator R&D at LBNL

S. Prestemon, D. R. Dietderich, S. Marks, R. Schlueter
Lawrence Berkeley National Laboratory

The development of short-period superconducting undulators (SCU's) is critical to extend the capabilities of the ALS and to leverage future upgrades, and is a key component of a number of future synchrotron radiation sources, such as the proposed LUX at LBNL. In order to develop the requisite technology, SCU R&D efforts are currently underway at LBNL.

On-going research at LBNL concentrates on winding and protection issues that arise with designs using the most advanced superconductors currently available. A 6-period Nb₃Sn prototype currently under construction is described, including the winding methodology, passive protection system, and details of the manufacturing process that are specific to Nb₃Sn magnets. The need for field quality control is then discussed, together with analysis of some concepts currently being considered.

The superconductor plays a key role in all aspects of SCU design, from magnet design to cryogenic design and performance limitations in a ring. Calculated attainable fields are presented as a function of period, magnetic gap, coilpack assumptions (Cu/SC ratio, insulation thickness, conductor dimensions, etc.), and operating temperature. The cross-over point between cold-bore and intermediate-temperature vacuum chamber designs will be discussed in relation to anticipated beam heating/cryogenics. Specific case studies of calculated device performance for the ALS are described, including a period-doubling winding scheme. Finally, we provide a review of superconducting materials together with a discussion of some advantages and disadvantages of different materials and wire/cable configurations for SCU applications.

KRO_01

Superconducting Undulator R&D Collaboration Program In the United States

Basic Energy Science Facilities Superconducting Undulator Collaboration

Keith Hodgson, Principal Investigator

Kem Robinson, Project Manager

R.D. Schlueter*, D.R. Dieterich, S.A. Gourlay, M.A. Green, S. Marks, S.O. Prestemon,

D.S. Robin, R.M. Scanlan, C. Steier

Advanced Light Source, E. O. Lawrence Berkeley National Laboratory

E.R. Moog*, R.L. Kustom, S.H. Kim, S.-L. Lee, S. Sasaki *Advanced Photon Source, Argonne National Laboratory*

G. Rakowsky*, E. Johnson, S. Krinsky, J.B. Murphy, J. Skaritka, P. Wanderer, E. Willen

National Synchrotron Light Source, Brookhaven National Laboratory

J. Welch*, K. Bane, T. Rabeau, J. Safranek

Stanford Synchrotron Radiation Laboratory, Stanford Linear Accelerator Center

In recent years it has become apparent that superconducting undulators (SCU's) can have a profound impact on the performance of existing light sources as well as the design and performance of future ring and linac based sources. This promise can only be realized through a careful technical exploration of the close coupling of the accelerator physics and engineering issues of small gap devices on storage rings. Recognizing their common need, the four United States Department of Energy (DOE) light source facilities (ALS/LBNL, APS/ANL, NSLS/BNL and SSRL/SLAC) have prepared a coordinated plan, which distributes responsibilities so as to employ the core competencies and unique resources available at each lab. A basic program to explore the fundamental issues in machine physics and to develop viable technological advances to approaches in SCU manufacture as part of a 3 year. An expanded program includes the basic R&D as well as construction and testing of several design verification models. Part of this testing regimen would include installation of test apparatus on one or more storage rings for detailed studies of performance and predictive capabilities under realistic beam loading conditions. Such a program is envisioned to take 4 to 5 years. This expanded R&D program would add significantly to the level of confidence and certainty of expected performance for working devices, allowing DOE Basic Energy Sciences facilities to fully exploit and implement SCU's in a manner permitting the maximum enhancement of their scientific reach, capabilities, and lifetime through subsequent implementation. The presentation will discuss the goals, organization, and technical approaches the collaboration proposes to follow to advance the state-of-the-art of superconducting undulators.

*Denotes Senior Team Leader – Point of Contact

RRO_01

The planned beam tests with a superconductive undulator at ANKA and future plans

R. Rossmannith

Institut for Synchrotron Radiation - ANKA

At the beginning of next year (2004) it is planned to install a superconductive undulator (100 periods, 14 mm period length) in ANKA for test purposes together with a simple beam line for photon beam diagnostics. Presently the field measurements of the undulator in a vertical Dewar are under way. The undulator gap width can be varied without breaking the vacuum in discrete steps (starting from 16 mm gap width). During injection and ramping the gap can be opened to 25 mm. The heating of the beam will be measured by temperature sensors at the surface of the cryo-coolers. After the first successful test we plan to design a planar helical undulator.

SSA_01

Design for a superconducting planar helical Undulator*

S. Sasaki

Advanced Photon Source, Argonne National Laboratory

Much effort is underway in various laboratories to develop short-period superconducting undulators. The driving force of this kind of effort is based on the requirements from users who need brighter radiation with higher photon energies.

One of the ways to construct a short-period helical device is to use a bifilar solenoid. However, this scheme is not tolerable for storage ring type accelerators due to narrow horizontal aperture. Also, there might be difficulties of precise magnetic measurements due to the poor accessibility to the axis of an undulator. For these reasons, a planar device is more favorable.

In the workshop, we consider the possibility of fabrication of planar superconducting undulator for generating circularly polarized radiation. A conceptual design of such a device is presented.

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S. Sasaki, e-mail: sasaki@aps.anl.gov, FAX: (630) 252-9303

TSC_01

Expansion of the hard x-ray energy range of the 2.4 – 2.7 GeV SLS with superconducting undulators: prospects and limits

T.Schmidt

Paul Scherrer Institute, CH-5232 Villigen

The SLS provides high brilliant x-rays up to 18 keV with in vacuum permanent magnet undulators. The first is in operation with 24mm period and a minimum gap of 6.5mm reliable using high harmonics. Three undulators with 19mm period and minimum gaps of 5mm are under construction. For a new beamline the energy range should be extended to 25keV which would require a superconducting undulator with small phase error. Beside this sc undulators could be used in straight sections with larger vertical beta functions which are used so far for soft x-ray beamlines.

DSC_01

A helical undulator for the production of polarised positrons

D.J. Scott & J.A. Clarke

Daresbury Laboratory

Future linear colliders require positron sources up to two orders of magnitude greater than is currently available, being able to generate polarised colliding beams would also be of great benefit. Proposed schemes to meet the requirements involve an undulator to produce high energy gamma rays. The gamma rays are then used to create electron positron pairs in a thin target. If a helical undulator is used then the circularly polarised gamma rays can be used to create polarised positrons. Two designs have been examined based on super-conducting and permanent magnet technologies to produce a helical undulator of period length 14mm and an on axis magnetic field of 0.8T. The final devices will need to be approximately 100m long with a circular bore of about 4mm.

JSK_01

Superconducting Undulator Test Facility at the Brookhaven National Laboratory

John Skaritka, Payman Mortazavi, George Rakowsky

Brookhaven National Laboratory

The development of superconducting undulator (SCU) magnet technology has been determined to be of critical importance for the proposed National Synchrotron Light Source (NSLS) upgrade at the Brookhaven National Laboratory (BNL). NSLS has initiated a program to develop SCU Technology in collaboration with the Stanford Linear Accelerator Center (SLAC), Argonne National Laboratory (ANL) and Lawrence Berkley National Laboratory (LBNL). BNL's task is to test and evaluate SCU prototype performance, for magnets built by BNL and members of the collaboration.

Presented is the design of the vertical test system that is currently under development at BNL. The test facility may be configured for field mapping of SCU prototypes by use of a hall probe array or a vertical stretched wire system. The test facility will be capable of testing SCU prototypes up to 0.45 meters in length by use of pool boiling helium or cryogen free conduction cooling. Prototype magnets may be subjected to simulated operating conditions for current and future synchrotron radiation sources.

SST_01

Resistive Wall Heating of ANKA undulator

S. Ströhmer

Institute for Synchrotron Radiation - ANKA

The Angströmquelle Karlsruhe (ANKA) and ACCEL Instruments GmbH are developing a superconductive undulator for ANKA.

In this context the power deposited by the electron beam in the adjacent wall material is calculated with the help of some simplifying assumptions.

EWA_01

The cold bore superconducting wiggler of MAX-Lab

Erik Wallen

ESRF

The increasing demand for high fluxes of x-rays to perform crystallography and material physics at MAX-lab is being met with the MAX wiggler [1]. The MAX-Wiggler is a cold bore superconducting wiggler with 47 3.5 T poles and a period length of 61 mm and it has been constructed in-house at MAX-lab. The MAX-Wiggler has now been installed and commissioned on the 1.5 GeV MAX-II [2] storage ring at MAX-lab. This talk describes the design and performance of the MAX-Wiggler and also the studies of the effects of the MAX-Wiggler on the stored electron beam. The MAX-Wiggler cryostat is a pool type cryostat with a bath of liquid He where the boiled of He gas is used for cooling different parts of the cryostat. The consumption of liquid He is about 2.5 litres per hour at nominal working conditions with 200 mA of stored current in the MAX II storage ring. The effects of the wiggler on the stored electron beam have been neutralized by modifying the magnetic optics of the storage ring and the MAX-Wiggler is now in operation at MAX-Lab. The talk will also describe some of the experience gained during the construction of the insertion device.

[1] E. Wallen, G. LeBlanc, and M. Eriksson, "The MAX-Wiggler, a cold bore superconducting wiggler with 47 3.5 T poles., Nuclear Instruments and Methods in Physics Research A 467-468 (2001) 118-121.

[2] A. Andersson et. al., 'The MAX II Synchrotron Radiation Storage Ring', Nucl. Instr. and Meth. A 343 (1994) 644-649.

EWA_02

Thermal budget of a cold bore superconducting undulator for the ESRF

Erik Wallen

ESRF

The talk will describe the expected thermal budget of a small gap superconducting insertion device installed at the ESRF storage ring and also general principles for the heat load to small gap cold bore insertion devices.

The thermal loads to the cryogenic system stems from a number of different sources e.g. thermal radiation, synchrotron radiation, heating due to image currents, and conduction of heat through the different parts of the cryostat. Some effects, like thermal radiation and heat due to conduction through parts of the cryostat are relatively easy to quantify while others, such as the resistive wall heating and heating due to RF effects are more complex. The small gap of the superconducting undulator exposes the cryogenic system to potentially high heat loads due to synchrotron radiation from the upstream bending magnets and also resistive wall heating. The resistive wall heating is determined by the geometry of the vacuum system and the electrical conductivity of the surface of the cold bore vacuum tube as well as the beam filling pattern and bunch length of the stored electron beam. There is a dramatic difference between the heating due to the resistive wall heating with a uniform bunch filling pattern and a moderate charge per bunch compared to filling patterns involving few bunches and a high charge per bunch.

The heating due to induced RF phenomena from the beam in the cryostat depends on the geometry of the cold bore accelerator vacuum system and it is not evident how to calculate the expected heat load from this effect.

The cryostat will be cooled by local cryocooler units by conduction cooling which makes the design different compared to cryostats using a pool of liquid He.

There is yet no finalized design of the cryostat and cold bore vacuum system of the superconducting undulator to be installed into the ESRF storage ring and the topic is still under discussion. It is however evident that the design of the cryostat and the cold bore vacuum system is as important as the design of the superconducting coils since without a cryostat with controllable heat loads it will not be possible to operate the superconducting coils.

EWE_01

A 7T Multipole Wiggler for BESSY II : First Commissioning Experience

E. Weihreter

BESSY

A 7T multipole wiggler has recently been installed in the BESSY II storage ring to provide high flux hard x-ray photon beams for the local user community. This project has been realised in a close collaboration between the Budker Institute of Nuclear Physics in Novosibirsk, the Hahn Meitner Institut in Berlin and BESSY. The conceptual design of the wiggler is presented together with first operational experience after implementation into the BESSY ring. Specific problems related with the intolerably high beam induced LHe consumption of the device and their cures will be discussed. Results of some preliminary beam dynamical experiments are also given.

JWE_01

Some Aspects of Beam Generated Heating of Superconducting Undulators

J. Welch

SLAC

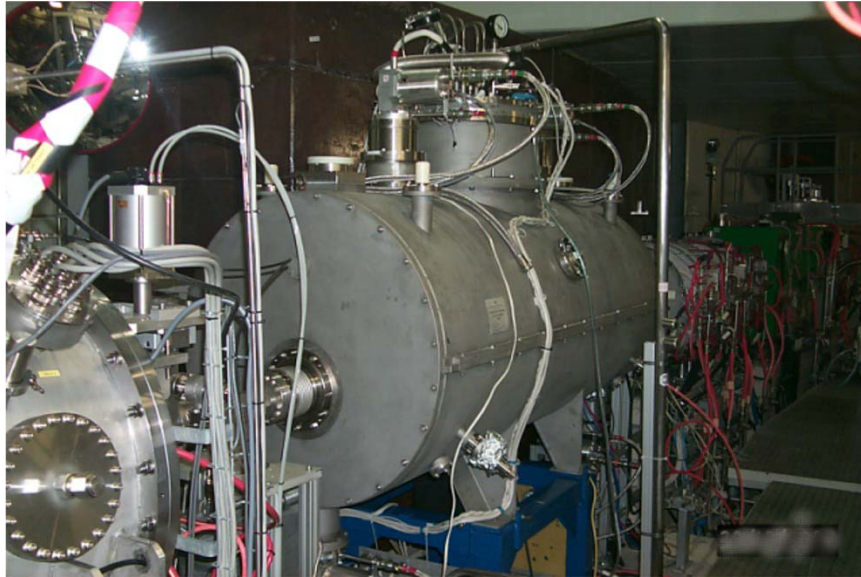
An optimised short period superconducting undulator would ideally have a cold bore. Radial space for insulation between the beampipe and the helium vessel, required for a warm bore device, can instead be used to reduce the magnetic gap and increase the undulator field strength. The major problem in a cold bore scheme is however, removal of heat at cryogenic temperatures. In this talk I will survey the sources of heat due to the beam that must be borne by the cryogenic system. Beam driven currents flowing in the inner wall generate much of the heat through the finite resistivity of the beampipe material. The low temperature and high magnetic field environment of the beampipe lead to some interesting solid state physics topics including, RF resistivity, anomalous skin effect, and magnetoresistance. Other heating sources that will be discussed include synchrotron radiation, lost particles, and electron cloud heating. Finally there will be a short discussion of the experimental possibilities for the measurement some of these effects in an existing storage ring.

DZA_01

The ELETTRA 3.5 T Superconducting Wiggler : assembling, installation and test results

D. Zangrando

Sincrotrone Trieste – Elettra



A 3.5 Tesla superconducting multipole wiggler (SCW) has recently been installed in the ELETTRA storage ring. It will be the radiation source for the new X-ray diffraction beamline. The presented wiggler, constructed by Budker Institute of Nuclear Physics, BINP (Novosibirsk, Russia) is a 49 pole superconducting magnet with maximum field of 3.5 Tesla. The main parameters of the magnet are :

Maximum field on beam axis (T)	3.5
Pole gap (mm)	16.5
Period length (mm)	64
Internal liner gap (mm)	10.7
Critical photon energy at 2 GeV (keV)	9.3
Total radiated power at 2 GeV, 100 mA (kW)	4.6

It consists of 45 full field (3.5 T) poles and 4 side poles (2.8 T and 1 T) to match the orbit. Inside the stainless steel vacuum chamber that is part of liquid helium vessel was installed a cold copper liner (20 K), with an internal vertical aperture of 10.7 mm, designed to absorb the thermal load from scattered photons and r.f. heating. The first vertical field integral along the wiggler can be adjusted using two power supplies.

The SCW was successfully tested at BINP in August 2002, in presence of the ELETTRA staff. After being disassembled and delivered to ELETTRA, it was reassembled and tested again to confirm the performance measured at Novosibirsk. In November 2002 it was installed and the commissioning started.

The SCW assembling carried out at Sincrotrone Trieste will be shown and the results obtained during the tests carried out before and after the installation will be discussed.