The Spallation Neutron Source Accumulator Ring RF System*

T. Hardek, M. Piller, M. Champion, M. Crofford

Spallation Neutron Source, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, U.S.A.
Phone: (865) 924-9806; FAX: (865) 241-6759
E-mail: hardektw@ornl.gov

A. Zaltsman, K. Smith

Brookhaven National Laboratory, Upton, New York 11973, U.S.A.

Abstract

The Spallation Neutron Source (SNS) accumulator ring is a fixed-frequency proton storage ring located at the output of the SNS Linear Accelerator (Linac). Its purpose is to convert 1 millisecond H- beam pulses from the SNS Linac into high-intensity 695 nanosecond pulses of protons for delivery to the neutron target. The RF bunching system controls longitudinal beam distribution during the accumulation process and maintains a 250+ nanosecond gap required for beam extraction. The RF system consists of three stations which operate at the beam revolution frequency of 1.05 MHz while a fourth station provides second harmonic component at 2.1 MHz. The beam pulse at extraction consists of 1.6e14 protons representing a peak beam current of 52 amperes. The system utilizes four 600kW tetrodes to provide the RF current necessary to produce the 40kV peak bunching voltage and to control phase and amplitude at this high beam current. In this paper we review the design concepts incorporated into this heavily beam-loaded RF system and discuss its commissioning status.

* SNS is managed by UT-Batelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy.

Status of the SOLEIL RF systems

C. Thomas Madec

on behalf of Synchrotron SOLEIL RF group
L'orme des merisiers
St Aubin, BP 48
F - 91192 Gif sur Yvette
+ 33 1 69 35 98 13/ +33 1 69 35 94 51
catherine.thomas-madec@synchrotron-soleil.fr

Abstract

The first operational results of the SOLEIL RF systems are reported. In the Booster the required RF accelerating voltage of 0.8 MV at 352 MHz is provided by a 5-cell copper cavity of the CERN-LEP type, powered with a 35 kW solid state amplifier. The amplifier consists in a combination of 147 modules of 330 W, based on a design developed in house, with MOSFET transistors, integrated circulators and individual power supplies. The Booster RF power plant, which was installed and commissioned in summer 2005, is fully operational. In the storage ring the 650 kW required RF power will be transferred to the beam through 2 cryomodules, each containing a pair of 352 MHz superconducting cavities. The RF power is supplied by 4 solid state amplifiers (4x724 modules), capable of delivering up to 190 kW. The first cryomodule and 2 amplifiers are being commissioned.

High-Power Solid-State Amplifier Developments at PSI

M. Gaspar, M. Pedrozzi, H. Fitze, W. Tron, M. Schneider

Hoch Frequenz Sektion, Paul Scherrer Intitut
CH-5232Villigen PSI - Switzerland
Phone: +(4156) 310 4036; Fax: +(4156) 310 3294
E-mail: marcos.gaspar@psi.ch

Abstract

This work presents the developments of high-power solid-state amplifiers at PSI aiming the future replacement of vacuum tubes and klystrons. The present work is being presently performed for an operating frequency of 500MHz. Results from 250W and 500W prototypes and a general description of the whole system will be presented. Target maximum power requirements in the final design will range from 20KW to 60KW. Other frequency ranges will be exploited later applying the same techniques as described in this work.

Update: RF Projects at Jefferson Lab

Richard Nelson, Alicia Hofler, Curt Hovater, Tomasz Plawski, Richard Walker,

Thomas Jefferson National Accelerator Facility, Newport News VA USA
757-269-7185 voice, 757-269-7352 Fax
nelson@jlab.org

Abstract

Facilities at Thomas Jefferson National Accelerator Facility in Newport News VA include a 6 GeV superconducting electron beam accelerator and a Free Electron Laser using similar superconducting accelerator technology. The present RF systems are CW operating at 1497 MHz, with RF powers ranging from 5 kW to 100 kW. Upgrades to these systems include an increase from 6 to 12 GeV for the main machine through the additional of 15 kW klystrons or IOTs, plus a new injector test stand for the FEL based on three 80 kW IOTs operating at 748.5 MHz.

Three approaches to delivering the additional power required for the CEBAF upgrade are presently under consideration. These include a single tube per cavity (our present topology) using either 1) klystron or 2) IOT, and 3) a higher power klystron capable of supplying power to multiple cavities, (typically 8). This latter option results in a more complex system and likely offers no cost savings.

New cryomodules will produce higher gradients, so in addition to a requirement for higher RF power new low level controls are also required. Design work is progressing on a new digital control system. 499 MHz editions are already operating satisfactorily on non-superconducting cavities including the IOT-based RF separators, and a prototype SC LLRF system will be tested on upgrade cryomodules. This paper will discuss these topics and other related items

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SPEAR RF Operation and Possible Changeover*

Sam Park

Stanford Linear Accelerator Center
Stanford, California 94309
1st author's Phone, Fax
spark@slac.stanford.edu

Abstract

The SPEAR upgrade plan was to store 500 mA at 3.0 GeV. In 2005 this goal was achieved briefly to verify the RF and other systems functionality. After a couple of control parameter adjustment the RF system satisfied all the requirements to sustain the beam. Until the beamlines are readied and there are demands for this high current, the user beam will be maintained at the present 100 mA level. On the operations side, there were a few problems with the RF subsystems that called for an elevated preparedness in terms of spare parts availability. Then bolstering the Booster RF system became an issue to improve the beam injection efficiency to the storage ring. Substituting a 358 MHz klystron running at a low power level with a solid-state amplifier is an option under consideration. Another is to match the Booster RF frequency to that of storage ring at slightly lower frequency. The implications of this changeover and a set of possible action plan are under consideration.

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Status of the ESRF Radio Frequency System

J. Jacob, J.-M. Mercier, P. Barbier

ESRF, BP 220, F-38043 Grenoble Cedex 09
Phone: ++33 4 76 88 20 42, Fax: ++33 4 76 88 20 54
E-mail: jacob@esrf.fr

Abstract

The ESRF operates a 352.2 MHz RF system with four 1.1 to 1.3 MW klystron transmitters connected through a switched waveguide network to one pair of five-cell cavities in the booster and three pairs of five-cell cavities in the storage ring. In standard operation with beam power up to 1 MW at 200 mA, one transmitter is kept as a spare and can be switched to the booster or the storage ring in case of problem with another transmitter. Most of the time it is available for the RF power teststand.

Based on trip statistics and the experience from years of operation, the RF system has been upgraded several times and is continuously being improved. This includes the development of sophisticated data logging, needed to support the diagnosis of failures.
This talk will focus on operational aspects of the ESRF RF system, including fault statistics and a summary of recent improvements. The question of klystron stock and procurement strategy will also be addressed on the background of a reliable functioning of our super klystrons over the last years.

Experience With the Klystron Procurements and Testing for the SNS Accelerator

Daniel Rees, William Roybal, Karen Young, Joseph Bradley, Mike Lynch, Paul Tallerico

Los Alamos National Laboratory
505-665-2802
drees@lanl.gov

Abstract

LANL was responsible for providing all the high power RF to the SNS accelerator. As part of our deliverables, we did four klystron developments. E2V provided a 2.5 MW peak power, 200 kW average power klystron at 402.5 MHz for the RFQ and DTL. Thales provided a 5.0 MW peak power, 400 kW average power klystron at 805 MHz for the CCL, and CPI and Thales provided eighty five (85) 65% efficient, 550 kW peak power, 55 kW average power klystrons at 805 MHz for the superconducting linac. The 5 MW klystron was a new state-of-the-art tube for combining high peak and average power and encountered difficulties. 105 klystrons in total were procured by Los Alamos for SNS. We site tested all of the high power klystrons to be installed at SNS and a significant fraction of the lower power tubes. All of the klystron procurements had technical challenges. The delivery schedule on the high power klystron procurements were delayed by over a year as a result. In two instances we negotiated consideration and/or reduced orders from the vendors, and in three of the four procurements we had to help the klystron vendors solve their technical issues to achieve the project milestones. The klystron requirements will be discussed. The problems and solutions will be presented and some of the lessons we learned will be discussed.

Modern and crowbarless DC power supply for continuous wave applications*

Wolfgang Tron

Paul Scherrer Institut, Large Research Facilities,
WLGA/030, 5232 Villigen PSI, Switzerland
Phone: +41 56 310 32 33; Fax +41 56 310 32 94
E-Mail: wolfgang.tron@psi.ch

Abstract

Thales designed and developed the Pulse Step Modulator (PSM) technique in order to provide regulated and audio modulated High Voltage DC power supplies. It is foreseen for different types of tube systems which are mainly tetrode-type broadcast transmitters and gyrotron tubes for microwave plasma heating. This type of power supply was adopted for 180kW CW klystron amplifier. Five of those amplifiers are in operation at the Swiss Light Source (SLS) since 2000. A functional description of the power supply and operational results will be presented.

* Part of the information is contributed by Thomson Broadcast & Multimedia AG 5300 Turgi / Switzerland

Performance Report on the 20kV/ 25A Anode Power Supply System Built for the KEK/ANL/ISIS Low Output Impedance Collaboration*

Doug Horan

Advanced Photon Source, Argonne National Laboratory,
Argonne, Illinois 60439, U.S.A.
Phone: (630) 252-7565; Fax: (630) 252-5948

Abstract

The design and performance of a 20kV/25A DC anode power supply designed and built for use in the KEK/ANL/ISIS Low Output Impedance Amplifier Collaboration will be presented. The power supply system utilizes a switching buck-regulator to achieve adjustable output voltage and current control, and a very fast series-opening output switch for overload protection. Operation of the power supply system under both DC and pulsed output conditions will be discussed. The design and performance of an IGBT-based control grid bias switcher used for gating the rf system final amplifier triode will be presented.

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150 kW Power Plant for the Elettra RF System Upgrade Project

Alessandro Fabris

Sincrotrone Trieste, SS 14 km 163,5 in AREA Science Park
34012 Basovizza, Trieste, Italy
Phone: (+39)040-3758221; Fax: (+39)040-3758565
E-mail: alessandro.fabris@elettra.trieste.it

Abstract

The 500 MHz RF system of the Italian third generation light source Elettra is now being upgraded. The upgrade will be performed gradually to avoid disturbances to the operation of the facility. For this reason the first step is the upgrade to 150 kW cw of one of the four plants.

The power amplifier will be realized combining two 80 kW IOTs (Inductive Output Tubes) by means of a switchless combiner. Although widely used in the broadcast market, only in the last years IOTs have started to be adopted for scientific applications. Each IOT will have its own power supplies allowing standalone to increase redundancy. The amplifier will be derived from broadcast transmitters and will be provided by industry.

This paper discusses the choices that have been made for the power plant components and gives an overview of the status of the Elettra RF upgrade project. The installation of the first power plant will be performed in the next months and the completion of the first phase of the upgrade is planned by the end of year 2006.

TRIUMF Cyclotron 23 MHz RF System Recent Improvements and Future Plans

Yuri Bylinski, Stevo Calic, Vladimir Zvyagintsev

TRIUMF, Vancouver, British Columbia, Canada
Phone: 604-222-7311, Fax: 604-222-1074
bylinsky@triumf.ca

Abstract

TRIUMF 23 MHz RF system has been running for more than 30 years providing about 1 MW of power for the 500 MeV cyclotron machine. In last few years the system and its components have gone through many improvements and modifications that cut down the RF downtime by factor of 3. Many troubleshooting and diagnostics elements have been incorporated into the system. One of them is 4-port coaxial RF switch, which required an upgrade to increase the transmitted power capacity by 50 %. It now allows switching the full RF power either to the cyclotron in normal operation, or to the dummy load for amplifier(s) high power test, tuning, and troubleshooting. Another notable upgrade was done to the amplifier output cavity. Extensive electromagnetic 3-D simulations using HFSS accompanied it. These and other RF system improvements as well as future upgrade plans will be covered in the presentation.

5 MW 805 MHz SNS RF System Experience

K. Young, J. Bradley, T. Hardek, D. Rees, M. Lynch, W. Roybal, P.Tallerico

LANSCE, Los Alamos National Laboratory, Los Alamos, New Mexico 87545
Phone: (505) 665-0141; Fax: (505) 665-28l8 Email: kareny@lanl.gov

Abstract

The RF system for the 805 MHz normal conducting linac of the Spallation Neutron Source (SNS) accelerator was designed, procured and tested at Los Alamos National Laboratory (LANL) and then installed and commissioned at Oak Ridge National Laboratory (ORNL). The RF power for this room temperature coupled cavity linac (CCL) of SNS accelerator is generated by four pulsed 5 MW peak power klystrons operating with a pulse width of 1.25 mSec and a 60 Hz repetition frequency. The RF power from each klystron is divided and delivered to the CCL through two separate RF windows. The 5 MW RF system advanced the state of the art for simultaneous peak and average power. This paper summarizes the problems encountered, lessons learned and results of the high power testing at LANL of the 5 MW klystrons, 5 MW circulators, 5 MW loads, and 2.5 MW windows.

Development of TEM High Power RF Vector Modulators for Charged Particle Accelerators*

Yoon Kang, Joshua Wilson, Sang-ho Kim, Michael McCarthy, Mark Champion

Spallation Neutron Source Project, Oak Ridge National Laboratory, Oak Ridge, TN, U.S.A.
Phone: 865-405-1714, Fax: 865-241-6759
E-mail: kangyw@ornl.gov

Abstract

The fan-out RF system may deliver significant cost reduction in construction and installation of the accelerators by reducing the number of power generators; a single high-power klystron feeds many cavities with individual RF vector control. To construct the vector modulators, a common waveguide or TEM coaxial type transmission line can be used with phase shifters employing either ferrimagnetic or ferroelectric materials. For frequencies in VHF/UHF range, the vector modulators can be built in coaxial transmission lines with advantages: reduction in dimensions, ease of cooling, etc. Development efforts of vector modulators for 402 MHz and 805 MHz that employ ferrite phase shifters in square coaxial transmission lines will be presented. Preliminary bench test has shown acceptable insertion loss and amplitude and phase control ranges. High power test of the vector modulator is to be made to demonstrate the power handling capability and control performance. The detailed designs and high power test results will be discussed.

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Coaxial switch, high power load and higher harmonic absorber for PROSCAN

Markus Schneider

Paul Scherrer Institut, Large Research Facilities,
WLGA/030, 5232 Villigen PSI, Switzerland
Phone: +41 56 310 35 50; Fax +41 56 310 32 94
E-mail: markus.schneider@psi.ch

Abstract

PSI's proton therapy project (PROSCAN) uses a gantry based spot scanning technique for irradiating deep-seated tumors. The new accelerator, a 250 MeV superconducting cyclotron, delivered by ACCEL will allow therapy throughout the year. The four-dee RF structure of the cyclotron is driven by a gridded tube amplifier chain, producing up to 150 kW of RF Power at 72 MHz. A simple coaxial device allows switching the amplifier between the cyclotron and a high power dummy load. To damp the higher harmonics in the coaxial line an absorber is foreseen. Design and operational results of the switch, dummy load and the higher harmonics absorber will be presented.

Power Test of a 325 MHz Hybrid for Fermilab Proton Driver

D. Sun, D. Wildman, R. Madrak (FNAL) and D. Horan (ANL)

Abstract

The front end of a proposed Fermilab 8 GeV proton driver consists of both room temperature and superconducting rf cavities operating at various power levels. An rf fan out is proposed to distribute power from one or two Klystrons to each rf cavity. IQ modulators are used to provide independent amplitude and phase control of individual cavities. Initial power test result of a stripline hybrid as part of IQ Modulator is presented.

Design and Applications of Polyphase Resonant Converter-Modulators

William A. Reass, David M. Baca, Robert F. Gribble

Los Alamos National Laboratory P.O. 1663, Los Alamos, N.M. 87545 (Ph) 505-665-1013, (Fax) 505-665-2818, wreass@lanl.gov

Abstract

High frequency polyphase resonant converter-modulators are a newly applied power conditioning technology. The first generation of 10 Megawatt pulsed, 1 megawatt average IGBT based systems were delivered to the Oak Ridge National Laboratory for the Spallation Neutron Source accelerator klystron RF amplifier system [1]. These systems utilized many new techniques [2] that are attractive to high power systems such as excellent efficiency, small size, and inherently self and load protective. A shorted load detunes the resonance and results in power flows that do not exceed the load joule fault rating or the converter component ratings, providing automatic fault ride-through capabilities. With high frequency transformers, the magnetic circuits can be less than 1% the size and weight of similar rated 60 Hz systems. This paper will review recent developments for IGBT based systems and extrapolate designs suitable for operating "CW" or parallel 10 MW long pulse klystrons, both with kilometer length output cables. In addition, MOSFET devices can also be utilized in higher frequency converter-modulators, that result in systems capable of ~250 kW "CW" in less than 20 cubic feet. The MOSFET based systems are high order switching systems (e.g. 12 pulse), such that system operation can continue, even in the event of multiple failed MOSFET switch cards.

High Power RF Systems in the Fermilab Linac

A. Moretti

Fermilab
Phone: 630-840-4843
moretti@fnal.gov

Abstract

A description of Fermilab's high power RF systems in use in the 400 MeV proton linac and an upgrade research system will be presented. The original 200 MeV, 201 MHz Fermilab proton linac was commissioned in 1970. It was upgraded in 1992 to 400 MeV with a section of Linac at 805 MHz. Recently, a research effort has been underway to upgrade the linac to 8 GeV using room temperature and superconducting cavities at 325 MHz and 1.3 GHz.

LINAC Commissioning with the SNS HPRF Systems*

M. McCarthy, R. Fuja, P. Gurd, T. Hardek, Y. Kang

Oak Ridge National Laboratory
Ok Ridge, TN 37831
(865)405-1328 Phone, (865) 241-6759Fax
mccarthymp@ornl.gov

Abstract

The SNS HPRF systems consist of transmitters controlling 92 klystrons that provide peak pulsed power from 550kW to 5MW to both the normal and superconducting linac. These systems were designed and specified for production by LANL as part of the multi-laboratory SNS construction phase and the initial start up of the HPRF systems was supported by LANL. This paper discusses the on-going HPRF operation in support of the linac and ring commissioning. We look at reliability, external system integration and software enhancements and briefly discuss the proposed SNS power upgrade.

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Clean up and Bead Pull of the LANSCE Coupled Cavity Linac Module 6

Karen Young, Gerald Bolme, Jim Billen, Lloyd Young

LANSCE, Los Alamos National Laboratory, Los Alamos, New Mexico 87545
Phone: (505) 665-0141; Fax: (505) 665-28l8 Email: kareny@lanl.gov

Abstract

During the start up of the LANSCE run cycle in January 2005, Module 6 of the 805 MHz coupled cavity linac was arcing and would not condition. An o-ring was found in the high field region of Module 6, Tank 8, between two nose cones. The visible o-ring was removed and the module was conditioned to the full power. In March, arcing problems re-occurred so the module was cleaned with a chamois soaked in alcohol. Module 6 was run from March to July with a high arc rate, up to 79 arcs per hour at 120 Hz.

In July 2005, an inspection, cleaning, bead pull to measure the electric field and x-ray measurements were done to try to reduce this arc rate. This paper discusses the results of the cleaning, and compares the electric field and x-ray measurements before and after the cleaning, and over the subsequent 7 months. The performance of Module 6 is now acceptable and has improved after the cleaning by reducing the number of arcs and VSWRs significantly.

The Partial Discharge Tests of the High-Voltage Cables and Other Components at the APS*

Alex Cours, Albert Hillman

Argonne National Laboratory
(630)-252-4550, (630)-252-5948 (Fax)
cours@aps.anl.gov

Abstract

An AC Dielectric Test Set (the Set) with a partial discharge (PD) detector was installed at the APS in January 2005. The Set has output rating of 40 kVAC, 75 mA. This Set is used on a regular basis for the following purposes:

1. Early detection of high-voltage (HV) cable insulation degradation, breakdown preventive maintenance.
2. Characterization of various HV connector types and selection of those with the highest PD inception voltage and lowest PD current values.
3. Testing of various greasing and insulating materials and techniques.

Use of the Set has helped us:

1. Find that the linac modulator HV cables can run without noticeable insulation degradation for a long time, despite the fact that the operating voltage is higher than the PD inception level of the cables.
2. Design and manufacture a set of PFN cables for the PAR kicker magnet upgrade project. The PD inception voltage of the cables is close to 40 kV, which exceeds project goals.

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352 Megahertz Test Stand at the Advanced Photon Source*

Ernest E. Cherbak

Argonne National Laboratory, 9700 South Cass Avenue
Argonne Illinois USA 60439
1-630-252-3706
eek@aps.anl.gov

Abstract

A 352 MHz RF Test Stand has been constructed and fully operational at the Advanced Photon Source at Argonne National Laboratory for approximately five years. The system provides CW rf power up to 1 MW for conditioning and components testing. The general layout of the system, as well as successes and failures during its commissioning and operation, will be discussed. Also future plans for an autonomous high power klystron and DC power supply system is envisioned since the test stand now employs a stand-by storage ring klystron for its rf power source. Highlights of a software program to minimize operator intervention during conditioning and overnight operations will be presented/

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The Installation and Commissioning of the IPNS Third Cavity*

M.E. Middendorf, F.R. Brumwell, J.C. Dooling, D. Horan, R. Kustom, M.K. Lien, G.E. McMichael, M.R. Moser, A. Nassiri, V.F. Stipp

Argonne National Laboratory, Argonne, IL 60439, USA
Phone: (630) 252-1683, Fax: (630) 252-9987
E-mail: mmiddendorf@anl.gov

Abstract

We report on the installation and commissioning of a third accelerating cavity system in the IPNS rapid-cycling synchrotron. In addition to providing operational flexibility and redundancy (i.e. three cavity operation at higher total available accelerating voltage and lower voltage per cavity, or two cavity operation with an on-line spare), the third cavity will provide a platform for second-harmonic studies. Plans to drive the third cavity at the second harmonic for the first portion of the accelerating cycle, and switching to the fundamental for the remainder of the accelerating cycle will also be presented.

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Bunch-by-Bunch Feedback and NC HOM Damped Cavities for a Current Increase at the ESRF

J. Jacob, E. Plouviez, G. Naylor, J.-M. Koch, V. Serrière, N. Guillotin

ESRF, BP 220, F-38043 Grenoble Cedex 09
Phone: ++33 4 76 88 20 42, Fax: ++33 4 76 88 20 54
E-mail: jacob@esrf.fr

Abstract

As part of a development strategy of the ESRF, it is planned to increase the maximum stored current. Besides photon absorber, vacuum and radiation safety issues, there are a number RF aspects, which will be addressed here.

At a medium time scale, the delivered beam will be raised from 200 to 300 mA. HOM driven longitudinal coupled bunch instabilities starting above 40 mA are currently suppressed up to 200 mA by means of a precise temperature regulation of the cavities to ±0.05 ºC. However, as no stable tuning can be found for higher currents, a bunch-by-bunch feedback system has been built up and is presently being commissioned: 250 mA could already be stored under stable conditions and grow/damp measurements indicate that 300 mA should be achievable easily. At a longer time scale, it is envisaged to increase the current at the ESRF even further, up to 400 or 500 mA. The existing ESRF five-cell cavities are no longer suited for the resulting high beam loading, and the gain of the longitudinal feedback cannot be increased sufficiently to fully control the HOM driven instabilities. Single cell copper cavities with strong HOM damping are therefore being developed at the ESRF, based on the BESSY design of such a cavity at 500 MHz. Following discussions at the third CWHAP meeting, it has been clarified that single cell cavities with temperature tuning of HOM are definitely excluded for the ESRF at very high currents.

The bunch-by-bunch feedback and the design status of the HOM damped cavity will be presented.

APS Particle Accumulator Ring Upgrades in Support of Improvement in Bunch Purity and Operational Reliability*

A.E. Grelick, E. Cherbak, N.P. DiMonte,

T.L. Smith, and C.Y. Yao

Advanced Photon Source, Argonne National Laboratory,
Argonne, Illinois 60439, U.S.A.
Phone: (630) 252-5862; Fax: (630) 252-5948
E-mail: grelick@aps.anl.gov

Abstract

The APS particle accumulator ring (PAR) uses two rf cavities. The fundamental cavity runs CW at 9.77 MHz. The harmonic cavity is pulsed with 117-MHz rf (twelfth harmonic), which compresses bunches of electrons for injection into the booster. The introduction of top-up operation of the APS has resulted in demands for improvements in both performance (in bunch purity, which is maintained over a wide range of beam current) and operational reliability. Several upgrades in support of these goals have either been incorporated in operational procedures and hardware or are under continuing study and experimentation. A software-controlled dual arbitrary function generator has replaced the dual manually controlled pulse generators in the harmonic subsystem, and the pulse timing has been changed substantially. These upgrades are discussed along with several others whose final configurations remain subject to continuing study and experimentation.

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Feasibility of Short Pulses at the ESRF

J. Jacob, L. Farvacque, E. Plouviez, V. Serrière

ESRF, BP 220, F-38043 Grenoble Cedex 09
Phone: ++33 4 76 88 20 42, Fax: ++33 4 76 88 20 54
E-mail: jacob@esrf.fr

Abstract

Among various schemes proposed for the production of short pulses, applying a chirped vertical kick by means of a deflecting cavity with a subsequent slicing or a compression optic is under consideration at several synchrotron light labs. At the ESRF, two possible ways of installing three NC backward wave S-band cavities operated with 0.5 μs long pulses at 1 to 3 kHz repetition rate, have been identified. In each case, it is foreseen to close the bumps after one straight section in order to limit the vertical beam blow up. These schemes will be described at the workshop together with some preliminary RF simulations, carried out to check if the HOM and the LOM of the structure can be sufficiently damped.

Superconducting Deflecting Cavities for Short X-Ray Pulse Generation at the Advanced Photon Source*

A. Nassiri, G. Waldschmidt

Advanced Photon Source, Argonne National Laboratory
(630) 252-6626
Nassiri@aps.anl.gov

Abstract

The Advanced Photon Source at Argonne National Laboratory is considering implementing of a "crab cavity" system based on Zholent's concept, in the APS storage ring to produce short x-ray pulses. Various rf configurations have been studied including single-cell and multi-cells deflecting cavities operating in TM110 mode. Initial simulation and analysis have been done including HOM and LOM damping. Our recent results on cavity and rf system design feasibility will be presented.

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