NewSUBARU Storage Ring

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Storage Ring Parameters

The machine parameters of the 1.5 GeV storage ring remain the same as those of the previous year. They are listed in Table I.

Table I Main parameters of the NewSUBARU storage ring in FY2009.

Circumference	118.73 m	
Bending lattice type	modified DBA	
Number of bending cells	6	
Straight sections	4m X 4,	15m X 2
Bending radius	3.22 m	
Injection energy	1.0 GeV	
Maximum energy	1.5 GeV	
RF frequency	499.955 MHz	
Betatron tune	6.30 (H),	2.21 (V)
Momentum compaction factor	0.0014	
Electron energy	1.0 GeV	1.5 GeV
RF voltage	140 kV	260 kV
Natural energy spread	0.047%	0.072 %
Natural emittance	38 nm	67 nm
Maximum beam current	500 mA	

Operation Status

The ring has two user-time operation modes, 1.0 GeV top-up operation mode and 1.5 GeV operation mode. Basic operation time is 9:00 - 21:00 of weekdays. Monday is for machine R&D, Tuesday is for 1.5 GeV user time, Wednesday and Thursday are for 1.0 GeV top-up user time, Friday is for 1.0 GeV or 1.5 GeV user time. Night period or weekend is used for machine study and user time with the special mode, single bunch operation and Laser-Compton Gamma ray, if necessary.

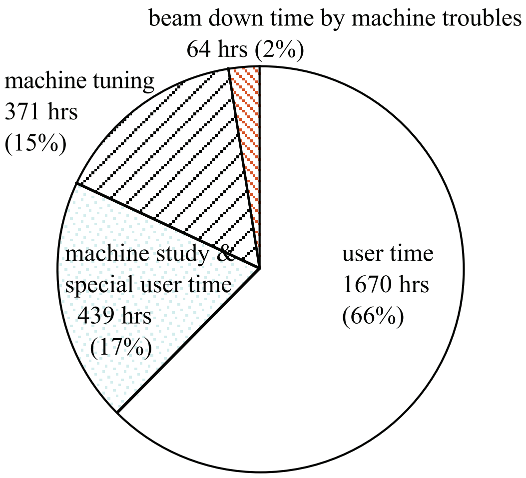

Fig. 1 Operation time in FY2009.

The total operation time in FY2009 was 2544 hrs, 105% of that of FY2008, including the beam down time. Fig. 1 shows the breakdown. The beam down time includes not only the down by a failure, but also off-beam periods by a beam abort or others due to the beam instability. The normal user time in this FY, 1670 hrs, was about 109% of that in FY2008. Time for machine study and special users was 80% of that in FY2008.

Machine Troubles

The machine troubles in FY2009 are listed in Table II. Many of sources of the failures in FY2008 were eliminated. The biggest failure was a vacuum break down by a miss-operation at BL09.

Machine Study and Special User Time

Table III shows the list of machine studies in FY 2009. One special theme, a research related to a production of Laser-Compton backscattering γ-ray and its use, took about 1/3 of the machine study time.

Most of the study reports are open to the public on the home page of NewSUBARU.

Accelerator Improvements

The ring had several improvements in FY2009.

Bunch current monitor, installed in FY2008 was organized to a new bucket filling control system. It controls the bucket-selector for the injection and realizes a wanted bucket filling.

The wave form monitor system, using LabView, is installed for the pulse bump magnet. The system can detect very rare miss-firing and abnormal wave deformation of pulse magnets.

The KEK-type XBPM was installed at BL10. It monitors vertical x-ray position from the bending magnet. It is expected to give information for the improvement of stability of the synchrotron radiation at beam lines.

The COD correction system started continuous working. It operates slow COD correction routine for every one minitues. The software has many sub-programs, which stops the continuous operation. They automatically stop the COD correction during the rapid injection, during the acceleration, and when the correction does not work properly by unknown reasons.

The visible light port SR5 for beam diagnostics, built in FY2008, was upgraded. It enables the detection of THz radiation at outside of the radiation shield. The corona graph elements were installed as a beam halo monitor.

Table II Machine trouble in FY2009.

Group	Failure/trouble	beam down time (hr)
Operation	Miss-operation	2
	Beam loss by a beam instabilities	3.6
RF	Interlock of circulator arc	0.3
	Interlock of klystron vacuum	6
	Klystron window chiller	1
Beam transport	Orbit feed-back	1
Vacuum	Vacuum leak at BL09	42
Radiation safety	Failure at BL02	2

Table III List of machine studies in FY2009. The unit of study time is counted by shifts (typically 12 hrs).

R＆D theme and special user mode	responsible person	study shift
Parameter tuning for 1.5 GeV acceleration	S. Hashimoto	3
Negative alpha-p operation	S. Hashimoto	2
Test of wave form monitor for pulse bump magnets	S. Hashimoto	1
Betatron tune feedback system	S. Hashimoto	6
Test of new COD control system	Y. Minagawa	1
Test of new filling control system	Y. Minagawa	1
Laser-Compton backscattering γ-rays (incl. Nuclear Transmutation)	S. Miyamoto	19
Test of bunch-by-bunch feedback system	T. Nakamura	1
Radiation shield for L4BT beam profile monitor	Y. Shoji	1
Vertical beam oscillation at the beam injection	Y. Shoji	1
Commissioning of new profile monitor port SR5	Y. Shoji	2
Commissioning of sextupole windings in the invert bends	Y. Shoji	8
Transverse beam matching at the beam injection	Y. Shoji	7
Effect of the magnetic shield for the DC septum stray field	Y. Shoji	1
Stored current dependence of COD	Y. Shoji	1

Beamlines

Takeo Watanabe and Hiroo Kinoshita

Total eight beamlines are operating in the NewSUBARU synchrotron facility. Four beamlines of BL01, BL03, BL06 and BL11 were constructed until 1999. Three beamlines of BL07, BL09 and BL10 were started the operation from 2000.

BL03B beamline branched from the BL03 beamline propose for the usage of the EUVL (extreme ultraviolet lithography) microscope for the EUVL finished mask inspection.

BL09B beamline branched from BL09 beamline propose for the usage of the advanced point diffraction interferometry for the test alignment of the EUVL imaging optics for practice use. Furthermore, BL09C beamline branched from BL09B for the usage of the EUV interference lithography to evaluate and develop EUV resist.

BL02 beamline was constructed for the usage of LIGA in 2003.

BL05 beamline was constracted in response to a demand in the industrial world, that is enhancement of the analysis ability in the soft X-ray region with the development of nanotechnology.

The arrangement of the beamlines in the NewSUBARU synchrotron radiation facility is shown in Fig.1.

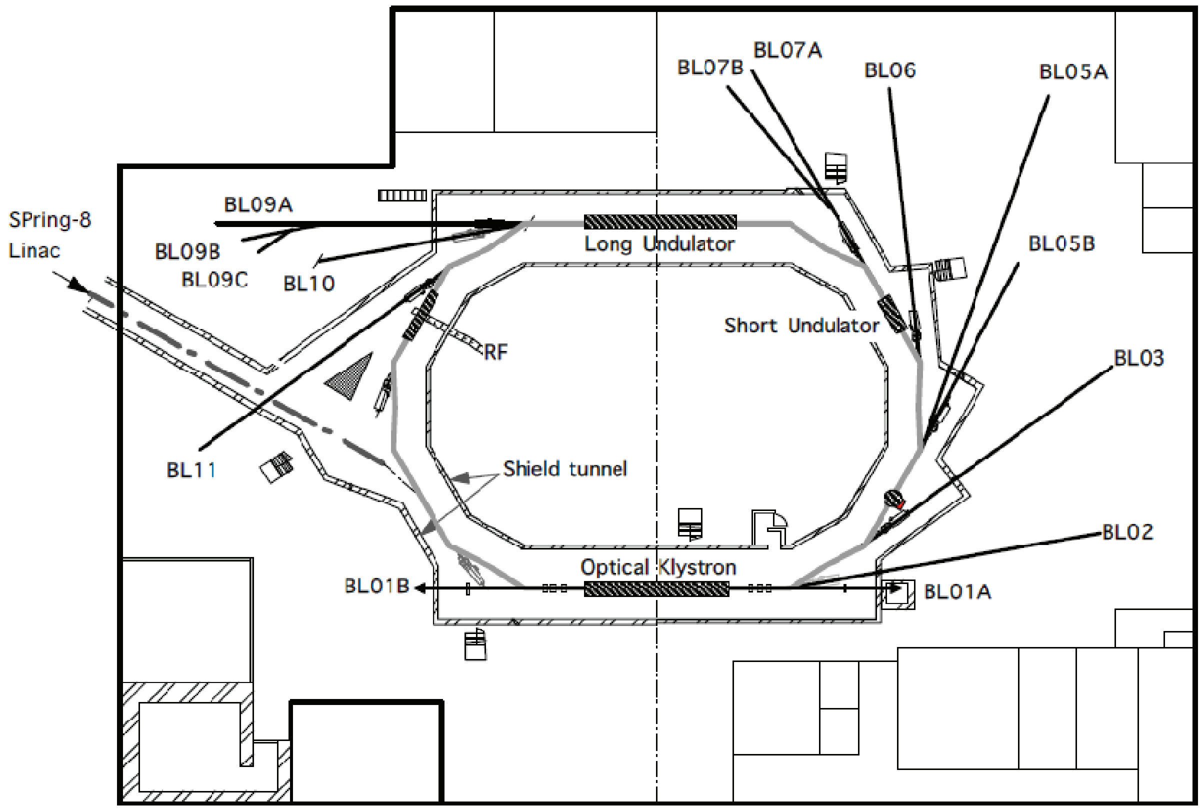

Fig. 1 Beamline arrangement in NewSUBARU.

I. BL01

BL01 is a beamline for research and developing new light sources. This beamline is one of two long straight section on NewSUBARU. Optical klystron was installed at this straight section. Upstream side of this beamline (BL01B) is intended to be used for visible and infrared light generated from FEL or SR.

Downstream side of this beamline (BL01A) is used for laser Compton scattering gamma-rays source. Gamma-ray beamline hutch just outside of the storage ring tunnel was constructed in 2004 for gamma-ray irradiation experiments. Specifications of this gamma-ray source are listed in Table 1.

Table 1. Specification of BL01 gamma beam

CO_2 laser 10.52 µm 5W	Gamma energy : 1.7 - 4 MeV Gamma flux* : 9 x106 γ/s : 6 x105 γ/s (1.5-1.7 MeV) (with 3mmφ collimator)
Nd laser 1.064 µm 0.532 µm 5 W	Gamma energy : 17 - 40 MeV Gamma flux* : 7.5 x106 γ/s : 3 x105 γ/s (15-17 MeV) (with 3mmφ collimator)

*Electron beam energy : 1-1.5 GeV
*Electron beam current : 250 mA
gamma-ray beam divergence : 0.5 mrad

II. BL02

The LIGA (abbreviated name of Lithogaphic, Galvanoformung and Abformung) process which consists from deep x-ray lithography, electroforming, and molding process is one of the promising candidates for such 3D micofabrication. More than hundreds aspect ratio for microstructure can be attained by the usa of the higher energy x-rays (4-15 keV) from synchrotron radiation (SR) with deeper penetration depth to the photosensitive resist. In this system we have succeeded to enlarged the exposure area up to A4 size and the fabrication dimension from submicron to millimeter by varying the energy of the x-ray source in accordance with the size of desired microparts. Micostructure with high aspect ratio over several hundreds will bi achieved using the x-rays over 10 keV since high energy x-ray has deep penetration depth to the photo-sensitive resist materials. Whereas, in the case of lithography for low energy x-rays from 1 keV to 2 keV, submicron structures with high aspect ratio will be achieved using the x-rays mask with precise line-width and thinner absorber, since low energy x-rays has low penetration depth. Based on this principle, the beamilne for x-ray exposure have constructed with continuous selectivity of x-rays frpm 100 eV to 15 keV by using the x-ray mirrors (plane and cylindrical mirror) and Be film filters. The horizontal angle of the outgoing SR could be obtained up to 12.5 mrad, which corresponds to the horizontal size of 220 mm (A4 horizontal size) at the exposure position. The second characteristic performance of the beamline is the high efficiency differential pumping system. This was necessary for maintain the vacuum difference between the storage ring ($<10^{-9}$ Pa) and the end-station ($<10^{-9}$ Pa) at which gasses for substrate cooling will be introduced in the exposure apparatus.

The flexibility for the shapes and functions of microstructure will be enlarged by achieving 3D microfabrication process using multi step exposure at various configuration between x-ray mask and substrates. The relative positions between x-ray mask and substrates, tilt and rotation angle to the SR incident direction can be moved simultaneously during SR exposure using 5 axis stages. The movement of each axis is controlled by the PC in terms of the scanning speeds, scanning length, and repetition number. In order to decrease the heat load of sample substrate suffered during SR irradiation helium introduction and substrate cooling mechanism were alse equipped. Specification of spectrometer is listed in Table 2.

Table 2. Specification of the LIGA exposure system

Optics	Plane and cylindrical mirror, Be filters
Exposure energy	100 - 2 keV, and 4 – 15 keV
Exposure method	Proximity and multi step exposure
Wafer size	A4 or 8 inch
Exposure area	230 mm(H) ×300 mm(V)
Exposure environment	< 1 atm (He-gas)

III. BL03

BL03 is a beamline for the developing the next generation lithographic technology so called extreme ultraviolet lithography (EUVL). The exposure tool is installed at the end station. Using this exposure tool, the research and development of the next generation lithography such as the less than 70 nm node is going on process. The exposure wavelength is 13.5 nm.

The semiconductor industry plays a very important role in the information technology (IT). In 2006, 256 Gbit DRAM with a gate length of 70 nm will be demanded in the IT industry. The extreme ultraviolet lithography (EUVL) is a promise technology for fabricating a fine pattern less than 70 nm. To meet this schedule, this technology has to be developed in the pilot line until 2004. As for the practical use, it is very important that both to achieve large exposure area and to fabricate fine patterns. Therefore, at Himeji Institute of Technology, large exposure field EUV camera consists of three aspherical mirrors was developed. First in the world, we fabricated 60 nm line and space pattern in the large exposure area of 10 mm×10 mm on a wafer. Furthermore, BL03B beamline branches from the BL03 beamline propose for the usage of the EUVL microscope for the EUVL finished mask inspection.

Table 3. Specification of the exposure tool (ETS-1)

Imaging optics	Three aspherical mirrors
Exposure wavelength	13.5 nm
Numerical aperture	0.1
Demagnification	1/5
Resolution	60 nm
Depth of focus	0.9 µm
Exposure area (static)	30 mm×1 mm
Exposure area (scanning)	30 mm×28 mm
Mask size	4 inch, 8 inch, and ULE 6025
Wafer size	8 inch
Exposure environment	In vacuum

IV. BL05

BL05 was constructed in response to a demand in the industrial world, that is enhancement of the analysis ability in the soft x-ray region with the development of nanotechnology. BL05 consists of two branch lines for use in the wide range from 50 eV to 4000 eV. BL05A and BL05B are designed to cover the energy range of 1300-4000 eV and 50-1300 eV, respectively. The incident beam from the bending magnet is provided for two branch lines through different windows of a mask. Therefore, these two branch lines can be employed simultaneously.

1) The double crystal monochromator was installed at the BL05A. InSb crystals and Si crystals are prepared for a double-crystal monochromator. Toroidal mirrors are used as a pre-mirror and a focusing mirror of BL05A. XAFS measurement in the total electron yield mode and fluorescence XAFS measurement using SSD (SII Vortex) can be performed. The fluorescence XAFS spectra can be measured for samples at the end station filled with He gas.

Table 4. Monochromator specification

Monochromator	Double crystal monochromator
Monochromator crystals	InSb(111), Si(111)
Energy range	1300-4000 eV
Resolution	E/⊿E=3000

2) The constant-deviation monochromator consisting of a demagnifying spherical mirror and a varied-line-spacing plane grating (VLSPG), which can provide high resolution, simple wavelength scanning with fixed slits, was mounted on BL05B. The optical system consists of a first mirror (M0), a second mirror (M1), an entrance slit (S1), a pre-mirror (M2), and three kinds of plane grating (G), an exit slit (S2) and a focusing mirror (M3). The including angle of the monochromator is 175°. Two measurement chambers are prepared at the end station of BL05B. The

XAFS spectra in the total electron yield mode and fluorescence XAFS spectra using SDD (EDAX) can be measured in a high vacuum chamber. In addition, the photoelectron spectrum can be measured using spherical electron analyzer (VG Sienta, R3000) in an ultra high-vacuum chamber. The chambers can be replaced by each other within 1 hour.

Table 5. Monochromator specification

Monochromator	Varied-line-spacing plane grating monochromator
Grating	100 l/mm, 300 l/mm, 800 mm/l
Energy range	50-1300 eV
Resolution	E/⊿E=3000

V. BL06

BL06 has been mainly developed for irradiation experiments such as photochemical reaction, SR-CVD, photo-etching, surface modification. The white radiation beam from bending magnet is introduced to the sample stage using a pair of mirror, whose incident angle was 3° . The SR at BL06 sample stage had a continuous spectrum from IR to soft x-ray, which was lower than 1 keV. A differential pumping system can be utilized for experiments in a gas atmosphere, which is difficult in the soft x-ray region. A sample holder can install four pieces of samples at a time. By using heater set in the sample holder, the sample can be heated from room temperature to 220°C. The temperature of sample is monitored using a Cr-Al thermocouple mounted on the sample holder.

VI. BL07A and BL07B

This beamline was designed for the development of new materials by SR technology. This beamline consists of two branch lines, which are provided with an incident beam from a 3-m undulator by switching the first mirror. One of them is a high photon-flux beamline with a multilayered-mirror monochromator for the study of SR-process (BL07A) and another is a high-resolution beamline with a varied line spacing grating monochromator for the evaluation of nano-structure characteristics by SR-spectroscopy (BL07B). The useful range of emitted photons from 50 to 800 eV is covered at both beamlines. The light source of BL07 is a 3-m length planar undulator, which consists of 29 sets of permanent magnets, a period length of which is 76 mm. The incident beam from the undulator is provided for two branch lines by translational switching of first mirror.

1) BL07A

The multilayered-mirror (MLM) monochromator, which has high reflectivity in the soft X-ray region, was installed at the BL07A. It consists of a switching mirror chamber, a slit chamber, a MLM monochromator, a filter chamber and a reaction chamber. To obtain a large photon flux, we decided to use only first mirror (switching mirror), M0, for focusing. The MLM monochromator is designed to cover an energy range of up to about 800 eV by combination of three kinds of mirror pairs with 4 kinds of filter. The flux deliver by this design is estimated to be between a maximum of 10^{17} photons/s at 95 eV and a minimum 2×10^{14} photons/s at 300 eV for a 500 mA ring current.

Table 6. Summary of BL07A.

<table>
<tr><th rowspan="2">Energy range (eV)</th><th colspan="5">Multilayer mirror</th><th colspan="2">Filter</th></tr>
<tr><th>Material</th><th>spacing</th><th>Thickness Ratio</th><th>number of layers</th><th>ΔE/E</th><th>material</th><th>thickness</th></tr>
<tr><td>50-60</td><td rowspan="2">Mo/Si</td><td rowspan="2">20 nm</td><td rowspan="2">0.8</td><td rowspan="2">20</td><td rowspan="2">6.2 %</td><td>Al</td><td>100 nm</td></tr>
<tr><td>60-95</td><td rowspan="2">None</td><td rowspan="2">—</td></tr>
<tr><td>90-140</td><td rowspan="2">Mo/B$_4$C</td><td rowspan="2">11 nm</td><td rowspan="2">0.5</td><td rowspan="2">25</td><td rowspan="2">3.3 %</td></tr>
<tr><td>140-194</td><td rowspan="2">Ag</td><td rowspan="2">100 nm</td></tr>
<tr><td>190-400</td><td rowspan="3">Ni/C</td><td rowspan="3">5 nm</td><td rowspan="3">0.5</td><td rowspan="3">60</td><td rowspan="3">2.5 %</td></tr>
<tr><td>400-560</td><td>Cr</td><td>500 nm</td></tr>
<tr><td>550-800</td><td>Ni</td><td>500 nm</td></tr>
</table>

2) BL07B

The constant-deviation monochromator consisting of a demagnifying spherical mirror and varied line spacing plane grating (VLSPG), which can provide to high resolution, simple wavelength scanning with fixed slits, was mounted on BL07B. The optical system consists of a first mirror (M0), a entrance slit (S1), a premirror (M1), and three kinds of plane grating (G), an exit slit (S2) and a focusing mirror (M2). The monochromator is designed to cover the energy range 50-800 eV with three gratings, of which including angle are 168°. The VLSPG has been well known to obtain high resolution in extreme ultraviolet region by diminishing various kinds of aberration. The total resolving power about 3000 can be realized in the whole energy region.

Table 7. Monocromator specification

Mount type	Hettrick-Underwood type
Grating G1, G2, G3	Plane VLS (600 l/mm, 1200 l/mm, 2400 l/mm)
Energy range	50-150 eV, 150 – 300 eV, 300-800 eV
Resolving power (E/ΔE)	～3000

VII. BL9

A purpose of this beamline is studies on a soft x-ray interferometry or a holographic exposure experiment with making use of highly brilliant and coherent photon beams radiated from 11 m long undulator in NewSUBARU.

BL09 consists of M0 mirror, M1 mirror, G grating and M2 and M3 mirror. M0 and M3 mirrors are used for horizontal deflection and beam convergence, M1 is used for vertical beam convergence at the exit slit, and M2 is used for vertical deflection and beam convergence. A monochromator is constructed by M1 and a plane grating. The maximum acceptance of the undulator beam is 0.64 mrad in horizontal and 0.27 mrad in vertical. The acceptance can be restricted by 4-jaw slits equipped at upstream of the M0 mirror.

BL09B beamline branched from BL09 beamline for the usage of the advanced point diffraction interferometry for the test alignment of the EUVL imaging optics for practice use.

BL09C beamline branched from BL09B beamline for the usage of the EUV interference lithography for the evaluation of the exposure characteristics of EUV resist. Coherence length of 1 mm at the resist exposure position was achieved using BL09C beamilne.

Table 8. Monochromator specification

Mount type	Hettrick-Underwood type
Grating	Plane VLS (900 l/mm)
Energy range	50 – 600 eV
Resolving power (E/ΔE)	～3000

Table 9. Specification of the BL09 End Station

Function	Extreme ultra-violet (EUV) point diffraction interferometry
Sample	EUV imaging optics. Presently, Schwarzschild optics.
Beam size	80(w) x 120(h) μm
Degree of Vacuum	5×10^{-4} Pa (differential evacuation system, upstream)
Photon number	1.2×10^{13} photons/sec, at 95 eV, Ie=40mA

VIII. BL10

BL10 is for the global use in the Himeji Institute of Technology. M0 mirror is used for horizontal deflection and beam convergence, M1 is used for vertical beam convergence at the exit slit, and M2 is used for vertical deflection and beam convergence. A monochromator is constructed by M1 and a plane grating. At the beginning, the multiplayers reflectiveity measurement was carried out at this beamline. The characteristics of this beamline and the result of the Mo/Si multiplayers measurement are carried out for the development of the EUVL mask techmology.

BL10 utilizes a monochromator of the varied line spacing plane grating monochromator (VLS-PGM). The line density of the monochromator in central region of the grating is 600 lines/mm. The reflectometer is a two axis vacuum goniometer using two Huber goniometers. One axis carries the sample, which may for examplee be a mirror at the center of the reflectometer vacuum tank (θ-motion). The other (φ-motion) carries the detector on a rotating arm. In addition there are through-cacuum linear motions to translate the sample in two orthogonal directions (x,y). All motors are controlled by computer. The sample itself is mounted on a kinematic holder. The controlstage monochromator rotation, and data analysis were program using LABVIEW software. The reflectivity result obtained at BL10 has a good agreement with that at LBNL.

Table 10. Monochromator specification

Mount type	Hettrick-Underwood type
Grating	Plane VLS (600 l/mm)
Energy range	50 – 600 eV
Resolving power (E/ΔE)	～1000

IX. BL11

A beam line BL11 is constructed for exposure Hard X-ray Lithography (DXL) in the LIGA (German acronym for Lithographite Galvanoformung and Abformung) process. LIGA process, that utilizes a useful industrial application of SR, is one of the promising technologies for fabrication of extremely tall three-dimensional microstructures with a large aspect ratio. This process was invented at the Institut Fur Mikrostrukturtechnik (IMT) of the Karlstuhe Nuclear Center (KfK) in 1980. Microstructures with height of over a few hundreds μm have been widely applied to various fields such as micro-mechanics, micro-optics, sensor and actuator technology, chemical, medical and biological engineering, and so on. This beam line was designed by the criteria ; photon energy range 4 keV to 6 keV, a beam spot size on the exposure stage ≥ 50×5 mm^2, a density of total irradiated photons ≥ 10^{11} photons/cm^2. BL11 of an absorber chamber, a first-mirror chamber (M1), a second-mirror chamber (M2), a 4-way slit chamber, a Be window chamber, and an exposure chamber. The second pre-mirror is bent elliptically using a bending mechanism. Fine bending adjustment of the M2 mirror can be made in the UHV by the pulse motor. The LIGA process needs the photon energies of 3 keV to 6 keV, the optics of a LIGA beam line generally employ a Pt monolayered-mirror and a Be window, which cuts off low-energy photons. The reflectivity of a Pt-coated mirror is about 55 % in the range of photon energy from 2 keV to 4 keV, however, it drops to 30 % at the photon energy of 6 keV. Therefore, new materials with a high reflectivity must to be found for Deep X-ray lithography (DXL) in this energy range. We propose the use of a Ni/W/C multilayered-mirror with a graded d-spacing in the range of photon energy from 3 eV to 6 keV. The calculated reflectivity of the Ni/W/C multilayered-mirror is higher than 56 % at the photon energy of 6 keV with a glazing incident angle of 0.8 degrees, and photons that have higher photon energy than 6 keV can be removed A 200 μm-thick beryllium (Be) window in a Be window chamber is used to separate the ultra-high vacuum part from the low vacuum part and to cut off low-energy photons.

Table 11. Specification of the LIGA exposure system

Exposure method	Proximity exposure
Wafer size	4 inch
Exposure area	50 mm(H)×80 mm(V)
Exposure environment	< 1atm (He-gas)

Improvement of beam injection using the injection bump waveform monitor at NewSUBARU

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Abstract

Although stable beam injections are necessary for the top-up operation of a storage ring, timing jitters and misfires were often observed in injection bump waveforms in NewSUBARU storage ring. Using a bump waveform monitor, we could find that timing jitters come from a timing signal module. By replacing this module, timing jitters can be drastically reduced from 1.9 % to 0.2 %. And no misfire of bump waveforms is observed now, although it occurred about ten times a day before. We are now always watching the waveforms of injection bump magnets by this monitor system to keep the stable top-up operation.

Introduction

In the NewSUBARU facility the top-up operation has been performed in the 1.0 GeV user time. The efficiency of beam injection has to be stably high for keeping the stored current constant. To realize this purpose, many kinds of stabilities are required, that is, stabilities of injection beam from linac, a pulse septum magnet, and injection bump magnets and so on.

In general, electron beams are injected to a storage ring using four pulse magnets called “bump” magnets, which make closed orbit of circulating beams at the injection point to shift horizontally for a very short period so that a beam from an injector can be successfully injected.

In the NewSUBARU storage ring, the number of beam injection exceeds over one thousand a day. Looking at bump waveforms in detail, little discrepancies in waveforms can be found. We developed bump waveform monitor [1,2] to watch bump waveforms. In this paper we report the improvement of the timing jitter and the misfire of bump waveforms by using this monitor.

Injection bump waveform monitor system

To get bump waveforms, an oscilloscope (Agilent TDS3054B) acquires monitor outputs of power supplies for bump magnets as shown in Fig. 1. Signals are externally triggered with beam injection pre-trigger signal. The oscilloscope is connected to a GPIB-Ethernet converter. A PC in the control room can communicate with the oscilloscope through local area network.

A software program developed with LabVIEW acquires, inspects in real-time and saves waveform data (Fig. 2). The other program analyzes each waveforms saved in PC and makes statistical analysis. This program can calculate a rise time (10-90%), peak-height, peak-position of each wavelength and show these distributions. Because bump is a high-voltage and pulsed magnet, acquired signals may be noisy. For noise reduction, data smoothing can be used before waveform analyzing.

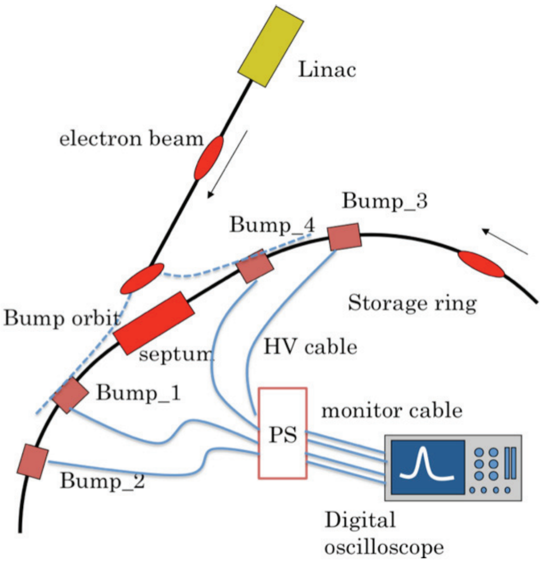

Fig.1. Electron beam injection from the SPring-8 linac to the NewSUBARU storage ring using four bump magnets.

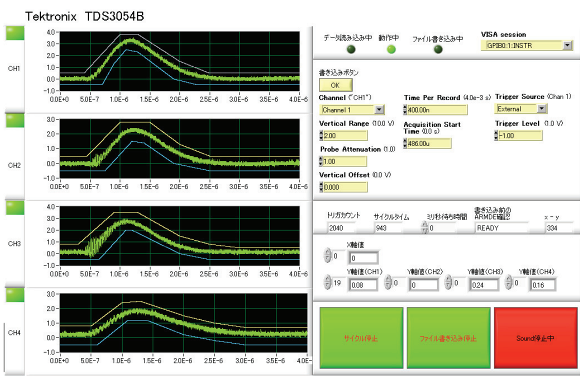

Fig.2. Front panel of the program for data acquisition, real-time inspection and data save.

Finding a trouble source with the monitor

The timing jitter and the misfire of bump waveforms may come from those of timing signals, in addition to failures of power supplies for bump magnets. To find the trouble source in timing signals, we checked signals form several NIM modules such as counter, FAN in/out, logical delay, and so on with the waveform monitor. The upper and lower limits in the monitor are correctly configured for testing digital signal waveforms.

As results, we found that a counter module (508 MHz, 30 bit counter) was a trouble source. After the new module replaced this one, no misfire of trigger signal form the module was observed.

Improvement of timing jitter of bump waveform

Peak-height, peak-position (timing jitter) and rise-time before and after the replacement of the troubled counter module are shown in Fig. 3. Standard deviations of these distributions are also shown in Table. I.

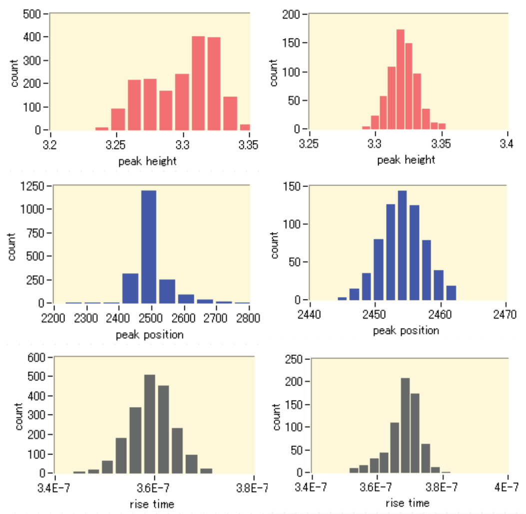

Fig.3. Discrepancies of bump waveforms in one day. Peak-height (top), peak-position (middle) and rise-time (bottom) are shown before (left) and after (right) replacement of the counter module. After the replacement, timing jitters of bump waveforms were drastically reduced.

Standard deviation (%)	Before	After
Peak position	1.9	0.2
Peak height	0.8	0.3
Rise time	1.2	0.9

Table I. Standard deviation of peak-position, peak-height and rise-time of bump waveforms before and after the replacement of the troubled timing module.

Although the standard deviation of peak-position was 1.9 % before the replacement, after the replacement its distribution became very narrow and its standard deviation was 0.2 %. Thus the timing jitter was drastically improved by replacement of the troubled module.

Improvement of misfire of bump waveform

Although no misfire was observed at the new module after the replacement, misfire of bump waveforms was still observed about ten times a day. However, misfire of bump magnets suddenly disappeared in March 2010. We suspicious that it was due to some troubles in the other modules or a loose connection of cables.

Summary

Various kinds of high stabilities are necessary for the stable top-up operation of storage rings. In the NewSUBARU storage ring we could find the source of timing jitter and misfire of bump waveform using the bump waveform monitor. By replacing the troubled timing module, the jitter becomes drastically small. Although misfire of the bump waveform was observed about ten times a day after the replacement, this suddenly disappeared. The reason may be due to the other timing module or a loose connection of cables, etc.

Now we are always watching bump waveforms during user operation using the bump waveform monitor. If there is something wrong in beam injection, quick search of trouble sources and quick recovery can be possible.

References

[1] T. Shinomoto *et al.*, Proc. of Particle Accelerator Society of Japan, (2009).

[2] S. Hashimoto *et al.*, LASTI Annual report, vol.9, (2009).

Development of automatic tune measurement and correction system at NewSUBARU storage ring

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Abstract

The automatic measurement and correction system for betatron tunes has been developed in NewSUBARU electron storage ring. Tunes are evaluated by analyzing beam signals from a beam position monitor. If differences between measured tunes and desired ones are large, tunes are automatically corrected using winding coils for ring quadrupole magnets Q1, Q2. We have successfully demonstrated that tune shifts can be suppressed using the system during an energy ramping.

Introduction

One of important parameters of a storage ring is betatron tune, i.e., the number of horizontal or vertical oscillations of stored electron beams around a closed orbit during one turn of the ring circumference. If tunes are not correctly adjusted, some troubles in the operation of storage rings, including degradation of beam lifetime, beam loss by instabilities, may occur.

In NewSUBARU electron storage ring, horizontal and vertical tunes are 6.30 and 2.23, respectively. However, tunes vary according to stored beam current and filling pattern. And during energy ramping from 1.0 to 1.5 GeV, fluctuations of electron beam orbit and tunes are relatively large. Sometimes these cause slight or critical beam losses.

To make the energy ramping stable, we have developed an automatic tune measurement and correction system. In this paper we report the system and experimental results of the automatic tune correction during energy ramping.

Automatic tune measurement system

The automatic tune measurement system is shown in Fig. 1. Horizontal and vertical betatron tunes are measured by BPM (beam position monitor) signals. We use a difference

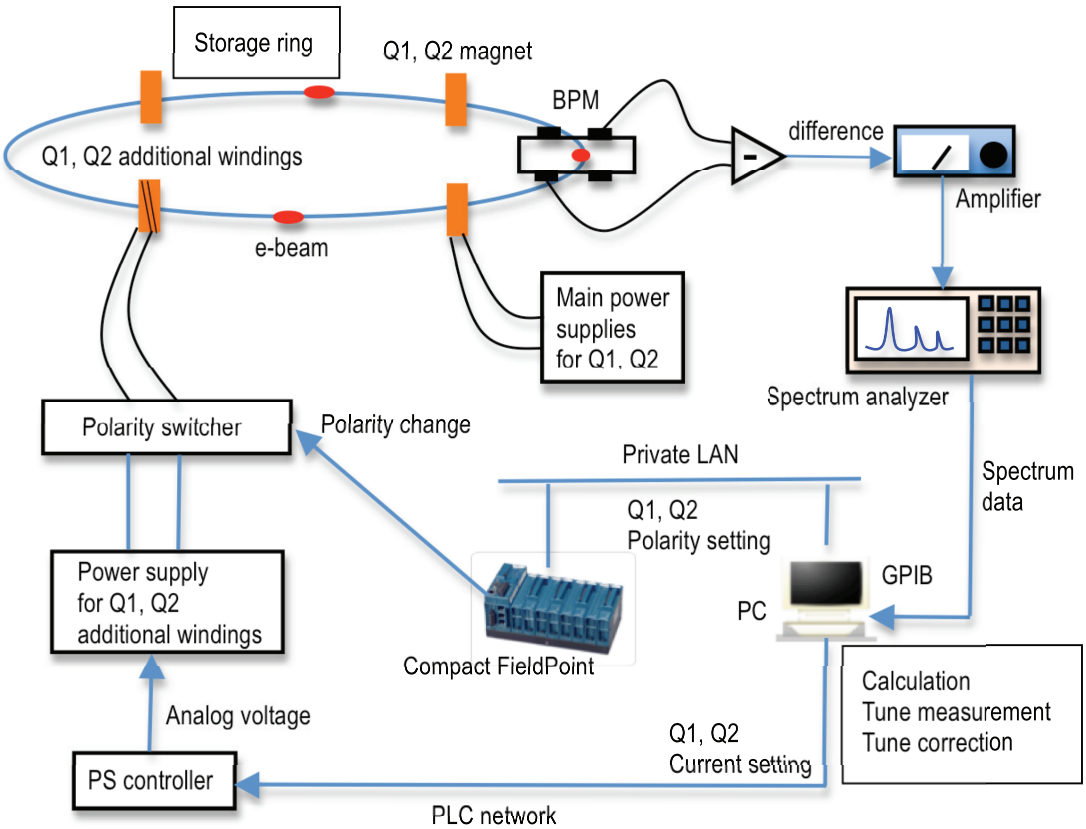

Fig. 1. Automatic tune measurement and correction system.

between signals from two diagonal electrodes of a BPM. The difference signal is analyzed in frequency domain by a spectrum analyzer. Spectrum data is transferred to a PC via GPIB. At the PC, the LabVIEW application program automatically detects two signal peaks around RF frequency and evaluates horizontal and vertical tunes in every 50 msec. Because the raw data for spectrums is relatively noisy, we use both averaging and smoothing methods in the signal processing. The measured tune values can be saved to a database every one second.

Automatic tune correction system

The configuration of the automatic tune correction system is also shown in Fig. 1. In the NewSUBARU storage there are seven families of quadrupole magnets. For tune corrections we used two families Q1 and Q2. Additional windings are equipped to Q1, Q2 magnets and additional power supplies feed current to these winding coils. A correction program on the PC calculates tune shift $\Delta\nu_x$ and $\Delta\nu_y$ which are differences from nominal values. Then currents fed to Q1, Q2 winding coils are given by the following equations:

$$I_{Q1} = E*(4.58E5*\Delta\nu_x + 6.03E4*\Delta\nu_y) + I_{Q1(old)},$$

$$I_{Q2} = E*(7.00E4*\Delta\nu_x + 5.06E4*\Delta\nu_y) + I_{Q2(old)},$$

where E is beam energy, I_{Q1}, I_{Q2} are currents fed to Q1, Q2 winding coils, respectively. The above equations were evaluated by comparing kick strength by additional winding coils and results of lattice calculations.

The PC sends calculated values of I_{Q1} and I_{Q2} to the controller every one second via a PLC network. The controller generates the equivalent analog voltage, by which power supplies for Q1 and Q2 windings are externally controlled.

To correct tunes both positively and negatively, the power supplies should be bi-polar. We used mono-polar power supplies with a polarity-switcher, which includes relay circuits and can control polarity according to external control signals, which are given by National Instruments Compact FieldPoint.

Tune correction during energy ramping

Measured tunes during energy ramping, which takes about 15 minutes, are shown in Fig. 2. Without tune corrections, variations of horizontal and vertical tunes were about 0.02.

With tune corrections, tune shifts became small and were within 0.005. Thus betatron tunes could be kept almost constant during energy ramp by this system.

Summary

We have developed the measurement and correction system for betatron tunes in the NewSUBARU storage ring. This system can measure horizontal and vertical tunes every 50 ms and correct tune shifts every one seconds. During energy ramping from 1.0 to 1.5GeV, tunes are successfully corrected within 0.005 with this system.

This system also can correct tune shifts in current decay operations. Furthermore, as applications of this system, an automatic tune survey is possible, which can automatically measure beam lifetime or injection efficiency at various operating points in a tune diagram.

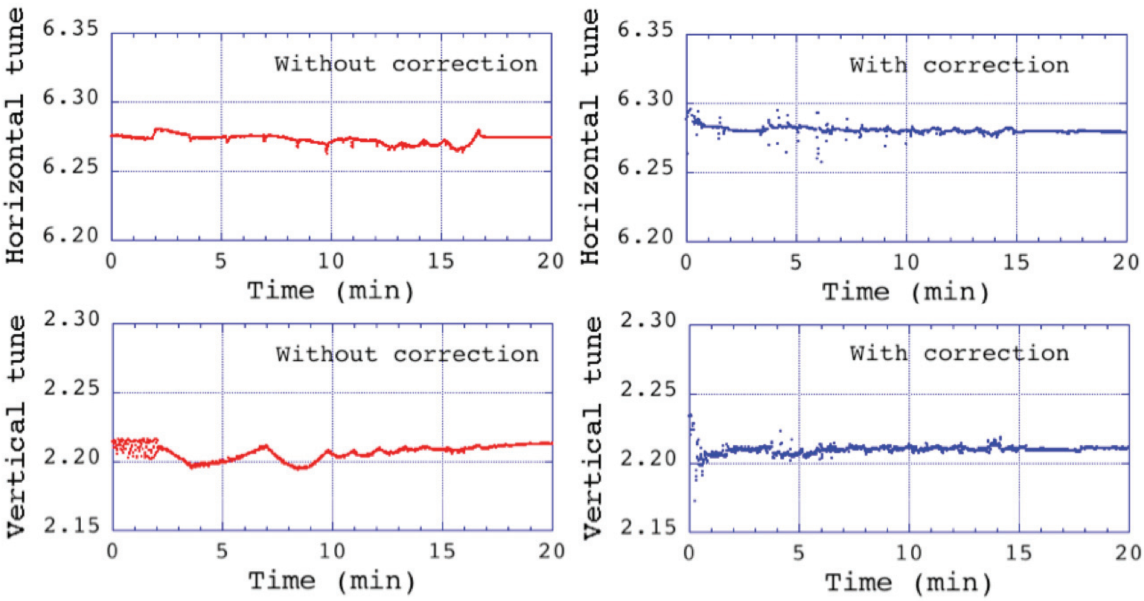

Fig. 2. Horizontal (upper) and vertical (lower) tunes during energy ramp without (left) and with (right) the automatic tune corrections.