UPGRADING OF A VACUUM SYSTEM OF THE NewSUBARU STORAGE RING : DESIGN AND EFFECT

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Abstract

The second upgrading of the vacuum system in 2001 resulted in a remarkable improvement of beam lifetime. Before designing the new system we calculated a vacuum pressure distribution around the ring based on measurements in many kinds of situations. We determined the final upgrading plan based on calculations in some cases. Three points of the upgrading were: (1) addition of pumping ports with pumps to bending magnet chambers (2) addition of pumping ports with pumps to vacuum chambers for long straight sections (3) use of many TSPs which have a large pumping speed. The calculation predicted that the vacuum pressure would be improved by a factor of 2.6. A plot of the product of beam current and beam lifetime versus the accumulated beam dose showed that the beam lifetime was improved by a factor of about 2. This was consistent with the prediction.

INTRODUCTION

The synchrotron radiation facility NewSUBARU [1, 2] is an EUV and Soft X-Ray light source at the SPring-8 site. Laboratory of Advanced Science and Technology for Industry (LASTI), at the University of Hyogo (previously Himeji Institute of Technology) is in charge of its operation, collaborating with SPring-8. The storage ring is a racetrack type with a circumference of 119 m and has two 14 m and four 4 m straight sections. We refer them by LSS and SSS. In the LSSs the 11 m long undulator (LU) and the optical klystron FEL (OK) have been installed. The ring has six bending cells. One cell is a modified DBA, one -8 degrees inverse bending magnet (IB) is set between a pair of 34 degrees bending magnets (NB) in order to control momentum compaction factor. The ring is operated in two modes for users. In 1.0 GeV top-up mode, the beam current is kept at 250$\pm$0.3 mA by an occasional injection with the gaps of the undulators closed. In 1.5 GeV mode, the beam is accelerated to 1.5 GeV and stored.

The vacuum system of NewSUBARU had been upgraded in 1999 [3]. The points of this first upgrade were (1) replacements of vacuum chambers of the insertion devices (2) installations and replacements of vacuum pumps. There had been a limitation of time for the replacement and we could not afford to replace vacuum chambers set at other than the insertions. However the first upgrading improved the pumping ability (vacuum pressure for the same gas load) by a factor of about 5.

Here we report on the second upgrading took place in 2001 that included reformations of bending chambers and straight chambers in focusing magnets. Considering the self-cleaning effect, the ring required an improvement of the vacuum pressure at least by another factor 2 to achieve a lifetime of 8 hours at 100mA until the end of 2002.

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VACUUM PRESSURE AND BEAM LIFE

Rough Estimation

We started designing the new system from a rough estimation of beam lifetime. The beam lifetime was 70 minutes at stored beam current of 80 mA in January 31 of 2001. The estimated contributions of Touschek and quantum effects were negligible. The pressure ratio at ccgs (cold cathode gauges) with beam (80 mA) to the base (0 mA) was 20~300. The product of the stored beam current (I) and beam lifetime (τ) was almost constant. It was clear that the total beam lifetime was determined by the increase of vacuum pressure from the photo-induced gas desorption.

Table 1: Ring Parameters of NewSUBARU

Circumference			119 m
Nominal stored electron energy			1.0 GeV
Averaged beta function		$<\beta_X>$	7.8 m
		$<\beta_Y>$	12.5 m
Beta function at the critical location		$\beta_X{}^m$	32 m
		$\beta_Y{}^m$	24 m
Vacuum chamber material	bending cell		mostly Al
	insertions		SUS
	injection		SUS
	RF section		SUS & Cu
Inner beam duct size at the critical location		$x_a{}^m$	$\pm$37 mm
		$y_a{}^m$	$\pm$10 mm
Momentum acceptance		$(\Delta P/P)_C$	$\pm$0.01%

The contributions of some kinds of scatterings of beam with residual gas molecules were estimated. We assumed that the residual gas molecules were H_2 and CO and that their partial gas pressures were 60% and 40% along the beam orbit. Using the ring parameters listed in Table 1, we estimated the lifetimes of Möller scattering (τ_M), Rutherford scattering (τ_R) and Bremsstrahlung (τ_B) for each of CO and H_2 for a total vacuum pressure P. The result is listed in Table 2. We concluded that the total beam lifetime was almost determined by the Rutherford scattering with CO mainly in vertical direction. The averaged partial gas pressure of CO for the total beam lifetime of 70 minutes was $1X10^{-6}$ Pa.

Table 2: Contributions of Möller scattering (τ_M), Rutherford scattering (τ_R) and Bremsstrahlung (τ_B) to beam lifetime

10^{-4} /Pa/hour	$1/(\tau_M P)$	$1/(\tau_R P)$	$1/(\tau_B P)$
60% H_2	4.8	4.8	1.5
40% CO	8.4	60	9.3

Model for Numerical Simulation

The vacuum pressure distribution along one of six bending sections was estimated. We chose the #1 cell, between the injection septum and the OK, because 8 ccgs and one quadrupole mass spectrometer were set along the cell to estimate the distribution. Fig. 1 shows the layout of #1 cell, which contains two NBs, one IB, and straight chambers for focusing magnets.

The one bending section was separated into 196 segments. The gas pressure distribution was obtained by finding a condition with which the gas flow and the gas pressure distribution are balanced. The conductance of the vacuum chambers were analytically calculated for H_2 and CO.

The ratio of photo-induced gas desorption yield of CO and H_2 was assumed to be the same at any location. It was determined as CO : H_2 = 33% : 67% from the measured ratio at the mass spectrometer (CO : H_2 = 50% : 50%). The gas yield was determined as is listed in Table 3 in order to reproduce the measured pressure at ccgs. Here we assumed the sensitivity factor to H_2 as 0.45. The estimated gas pressure distributions of CO and H_2 along the beam trajectory are shown in Fig. 2. The weighted average of partial pressure of CO, $<P_{CO}\sqrt{\beta_Y}>/<\sqrt{\beta_Y}>$, was $5.1X10^{-7}$ Pa, about a half of the rough estimation. Possible reasons of the difference were the errors of ccgs and the overestimation of the ring acceptance (y_a^m in Table 1) [4].

Simulation of Improvements

We estimated the improvement of $<P_{CO}\sqrt{\beta_Y}>/<\sqrt{\beta_Y}>$ using the model. The results are shown in Fig. 3. Just an upgrade of vacuum pumps was not effective. Even 10 times larger pumps improved the estimated $<P_{CO}\sqrt{\beta_Y}>/<\sqrt{\beta_Y}>$ to $4.5X10^{-7}$ Pa. New pumping ports at NBs and LSS were necessary to improve the averaged pressure. The following change improved $<P_{CO}\sqrt{\beta_Y}>/<\sqrt{\beta_Y}>$ to $2.3X10^{-7}$ Pa. (1) Add new ports at the middle of NBs with sputtering ion pumps (SIP, pumping speed of 0.2 m^3/s for CO). (2) Improve conductance of the ports at the up-stream end of NBs with SIPs (pumping speed of 0.2 m^3/s for CO). (3) Add new ports at LSS with non-evaporable getter pumps (NEG, pumping speed of 0.3 m^3/s for CO). For more improvement we added titanium sublimation pumps (TSP), which had high pumping speed 1.6 m^3/s for CO, at most of possible pumping ports. It would improve $<P_{CO}\sqrt{\beta_Y}>/<\sqrt{\beta_Y}>$ to $1.95X10^{-7}$ Pa. This improvement by the factor of 2.6 would clear the requirement. This became our final plan.

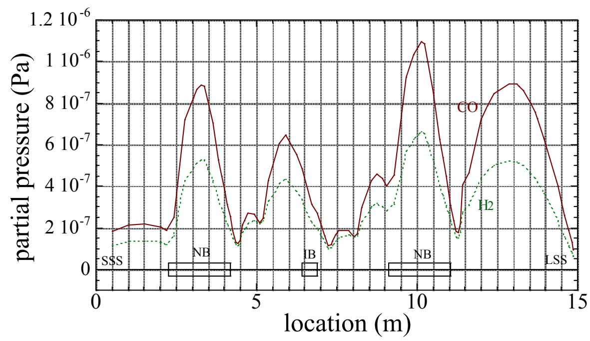

Figure 2: The estimated gas pressure distributions of H_2 and CO before the improvement.

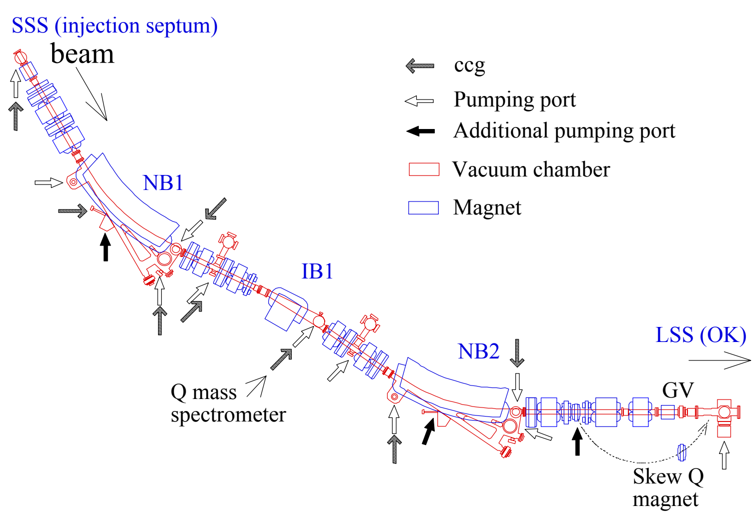

Figure 1: Bending cell #1.

Table 3: Assumed gas desorption yield

location	material	incident angle of photon	photon flux (angle from B)	yield
unit		degrees	degrees	10^{-5}molec. /photon
absorber in NB	Cu	90	35.6	0.22
absorber in IB	Cu	45	6.4	0.65
absorber in NB	Al	4	30.3	2.2
straight section	Al	< 4		
straight section	Al	< 2	3.7	6.5

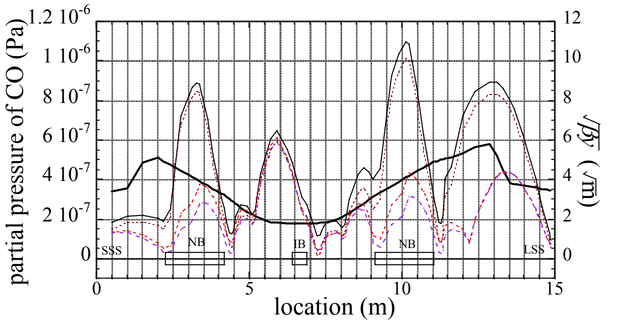

Fig.3 The simulation results of the improvement of gas (CO) pressure distribution. The thick line shows $\sqrt{\beta_Y}$ along the section. The thin top line is the distribution at before the improvement. The second line is that with 10 times larger pumps. The third line is that with the additional pumping ports. The fourth line is that with the additional pumping ports and the TSPs.

UPGRADING

Reformation of Vacuum Chambers

The Al support blocks attached to the bending chambers were removed and new pumping ports were put at the places. The small conductance of the pumping ports at the up-stream ends were improved by replacing narrow ducts by wider ducts. Before the re-installation of the bending chambers their deformations by welding the new ports were measured. The deformations were less than 0.5 mm, which were acceptable.

In order to make space for pumping ports on the straight chambers, the skew quadrupole magnets were moved to a space at just beside the OK and LU. We made holes on the straight beam chambers to put the new pumping ports.

We put TSPs in large pumping ducts at most of the pumping ports, including the ports for beam lines where the lines were not constructed. The duct lengths of the pumping ports were minimized to maximize the conductance.

Improvement of Beam Lifetime

The product of stored beam current and beam lifetime ($I\tau$) at before and after the upgrade is shown in Fig. 4. The improvement of $I\tau$ by the self-cleaning effect was on the lines of the plot. The improvement of the pumping ability appeared as a discontinuity of the lines. It had been improved by about a factor of 5 in 1999. At this time in 2001 it was improved by about a factor of 2.5. With this improvement we reached to $I\tau$ = 800 mA hr at 1.0 GeV, in November of 2002.

Here we should mention that the plot of Fig. 4 contains other effects than the self-cleaning and the upgrades of the vacuum system. The optimisation of the vertical acceptance in 2002 improved $I\tau$ by a factor of 1.5. The number of photons per stored current at 1.5GeV is larger than that at 1.0 GeV. However its effect was small because the operation time at 1.5GeV was less than 20%. Especially at the end of the plot the Touschek lifetime should be took into the consideration. In 2002 the Touschek lifetime was estimated to be twice of the lifetime of the Rutherford scattering. Considering those effect, we concluded that the present upgrading improved the pumping ability by a factor of about two.

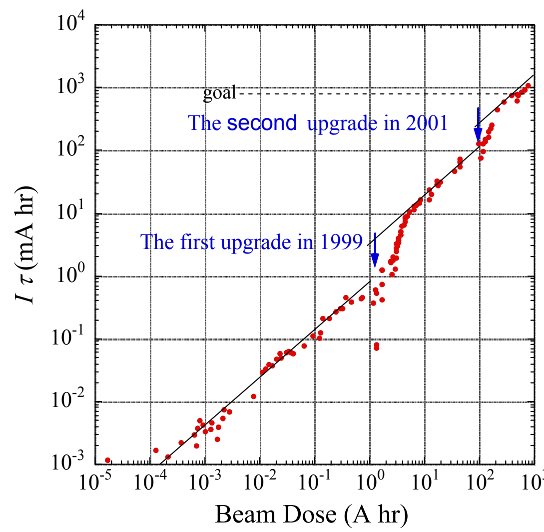

Figure 4: Improvement of $I\tau$ by self-cleaning effect. The lifetime was that at 1.0GeV. The upgrading of the pumping ability appeared as discontinuity of the line.

REFERENCES

[1] A. Ando *et al.*, *J. Synchrotron Rad.* 5, pp.342-344 (1998)

[2] Y. Shoji, *et al.*, “Operational progress of New-SUBARU in these three years”, this conference.

[3] S. Hashimoto, *et al.*, Nucl. Instr. & Meth, A467-468, pp. 145-148 (2001).

[4] Y. Shoji et al., “Improvement of beam lifetime at the NewSUBARU storage ring”, this conference.