MASTERING OF BEAM LOSSES AT THE ESRF

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Abstract

With the installation of 11 mm inner vertical aperture vacuum vessels in high beta straight sections a dramatic increase of bremsstrahlung outside the corresponding optic hutches was experienced. To maintain free access in the experimental hall only dose rates up to 2.5 μSv/h are allowed. The vacuum vessels were also highly activated.
With the help of a new beam loss detector system installed the transfer of horizontal oscillations into the vertical plane was identified to be the origin of the bremsstrahlung.
Limiting the vertical acceptance with scraper jaws proved to be effective to get rid of both bremsstrahlung and activation problems. As a second measure an increase of the vertical acceptance by applying a small vertical beta function in all straight sections was made operational which proved to be sufficient to suppress the bremsstrahlungs problem.
All the effort enabled the ESRF to operate safely with these small gap vessels in half of the straight sections and to test a new set of only 8 mm inner vertical aperture vessels. The presentation will contain the theoretical and experimental work performed on this topic.

1 BEAM LOSS MECHANISMS

1.1 Beam Loss Origins

The beam losses can be sorted in three major categories: beam losses during injection, beam losses during stable stored beam and beam losses in special conditions for example equipment failures or voluntary beam kills.
Injections losses occur when the injected electrons do not fall inside the longitudinal or transverse acceptance. At a typical injection efficiency of 80 % they are responsible for 20 % of the losses. Given the energy acceptance of the storage ring of more than 3 % most of the injection losses were measured to be due to transverse mismatching of the injected beam.
Among the different contributions to the lifetime limitation only four effects appeared to be relevant: elastic gas scattering, inelastic gas scattering, Touschek scattering and Compton scattering. In few bunch mode delivery the touschek lifetime is by far dominating the losses whereas during the standard multi bunch filling pattern all components stay within the same range. The Compton scattering of the electrons on photons takes only place if the GRAAL experiment which shoots with a laser on the beam is in operation. In that case the beam line is allowed to reduce the beam lifetime by 20 %.
Other major losses appear due to voluntary beam kill with a scraper jaw or equipment failures.

1.2 Quantification of losses

A sharing between the different beam loss origins was estimated based from experimental values as Mean Time Between Failures, the percentage, the intensity and the lifetimes of different operation modes and the machine studies program. Assuming an equal sharing between losses during user mode and losses during machine studies the following loss sharing was found:
31 % active beam kills
30 % injection losses
15 % Touschek scattering
11 % equipment failures
5 % GRAAL experiment losses
4% inelastic gas scattering
3 % vertical elastic gas scattering
1 % horizontal elastic gas scattering

Only the lifetime losses and the equipment failures contribute to radiation problems around the optic hutches in user service mode whereas the totally of losses is responsible for the chamber activation and radiation damage inside the tunnel.

2 BEAM LOSS POSITIONS

2.1 The beam loss detector system

To detect the losses a set of beam loss detectors were installed around the ring. The detection principle is based on the light creation in a scintillator material when a high energy particle crosses the detector volume. To suppress synchrotron radiation background the scintillator material is put in a lead protection. Two types of detectors were used:

- the first one measures large losses during injection and full beam loss and uses a photo diode as light collector. 96 detectors were installed around the ring: one at each straight section and one after each dipole.
- the second type measures small losses during stable stored beam and uses a photo multiplier as light collector. 32 of them were installed i.e. one at each straight section.

Experience showed that the detectors for small beam losses were not very reliable due to too important synchrotron radiation background and damage during interventions. Additionally the positioning at the entrance of the ID vessels did not allow to compare the losses from different cells due to the different chamber and placing configurations. In the moment an upgraded version with improved synchrotron radiation shielding is being installed and tested. The detectors are always put on the tunnel wall close to end of the straight section. First results show that the synchrotron radiation background was suppressed and that in case of loss changes the signals of the detectors act correspondingly.

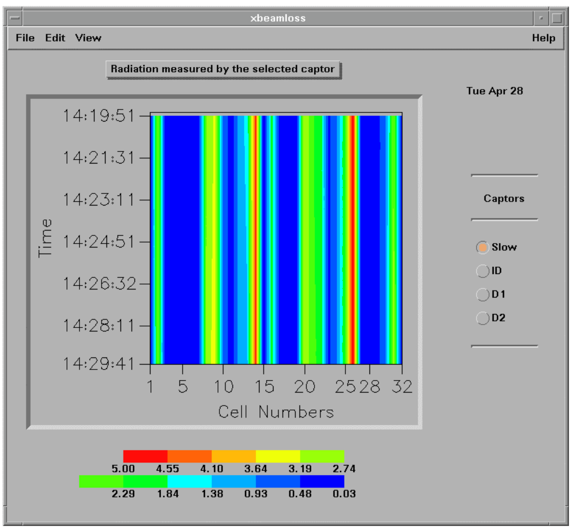

Figure 1: Application showing the beam loss distribution

2.2 Important parameters

Several parameters determine the collision point of a scattered electrons with the vacuum chamber:

- the travelling length between the initial scattering point and the final collision. If the travelling is long compared to the ring circumference all electrons will end on the aperture limiting point.

Energy losses and resonance losses will cause losses after many turns whereas electrons having a large betatron amplitude following one interaction will not go far.

- the source point. The source point plays an important role if the collision point is not far downstream the source point. For injection losses the septum can be considered as source point whereas stable stored beam losses have distributed source points.

- finally the aperture distribution contributes a lot. If there is one dominant aperture limitation in one plane most of the electrons will be lost on it.

In the horizontal plane the septum sheet was by far the limiting factor in the horizontal plane. In the vertical plane the 11 mm inner aperture vessels in the high beta straight sections became the limiting elements

2.3 Scraping effect of a single chamber.

A vacuum chamber of the length 2 D and half aperture d has for a minimum beta function β in the middle of the chamber a total acceptance of $A = \left(d^2 \cdot \beta\right) / \left(\beta^2 + D^2\right)$. If the beta function is equal to half of the length of the vacuum vessel the total acceptance becomes maximum.

In high beta straight sections with a beta function of 13.25 m there is a high probability that electrons with large amplitudes can still go on.

2.4 Tune shift with amplitude

Beam Losses due to Touschek scattering were found to take place in the vertical plane. An explanation was found when looking to the tune shift with energy. Electrons with 3.5 % energy reduction find their vertical tune reduced from the nominal 11.39 to 11.00. Knowing that the integer resonance is killing the beam this results in the fact that scattering effects with energy losses finally lead to a vertical oscillation.

This tune shift with amplitude effect was found to be the energy acceptance limiting effect. Consequently the majority of electrons losses ended up in losses on Insertion Device chambers.

2.5 Detailed loss positions

The final loss positions could be derived for the different effects:

- vertical elastic gas scattering:
  majority of losses on the new insertion device vessels in the high beta straight sections in a distributed manner
- vertical injection mismatch:
  losses on the chambers in cells 6,8,10,12,14,16, and 18
- horizontal elastic gas scattering:
  septum sheet and to lesser extent inside the high horizontal beta sections of cells 5, 7, 9, 11 and 13
- longitudinal losses during injection
  losses on new insertion device vessels.
  Distribution unpredictable to optic distortion on resonance
- Touschek and inelastic gas scattering:
  majority on new Insertion Device vessels
  important part on septum sheet
  small part inside the high horizontal beta sections

2.6 Interactions on chamber walls

Simulations were done to investigate the collision of the electrons on a chamber wall. One important result was that if the impact takes place with a rather small angle there will be large part of electrons which will be slightly scattered and only loose a small fraction of their energy[1]. These electrons have the potential to be lost downstream. This effect was measured when closing a scraper jaw.

3 LOSS REDUCTION MEASURES

3.1 Low beta optics

One major change towards reduced losses was the switch to an optics with 2.5 m vertical beta function in the middle of the straight section[2]. This is the optimum value in terms of vertical acceptance for the 5 m long vessels. This directly increased the vertical elastic gas scattering lifetime and the acceptance for vertical missteering during injection. Following this reduction of the beta function the resistive wall effect was lowered enabling to reduce the vertical chromaticity which increased the energy acceptance for off momentum particles.

3.2 2/3-filling mode

The main filling pattern was changed from a 1/3 filling to a 2/3 filling thus doubling the Touschek lifetime.

3.3 Injection septum displacement

The septum sheet was placed further away from the beam (19.5 mm instead of 13.5 mm). This increased the transverse acceptance and therefore the touschek and inelastic gas scattering lifetime.

3.4 Refill procedure

Due to an improved refill procedure beam kills during injection time became obsolete for some filling patterns.

3.5 Limitation on injected beam

Based on radiation calculations the amount of injected electrons into the storage ring was limited to 12 µC per 4 hour period. For some injection intensive machine studies this resulted in less losses.

4 PROTECTION WITH SCRAPERS

One of the first actions was to use the existing scraper in the machine to concentrate the losses on it[3]. Using the vertical jaws proved to be very efficient to remove the large majority of losses from the insertion device vessels.
A strategy was adapted which consists in closing all available scraper jaws to a position which hardly reduces the lifetime during stable stored beam. During injection the scraper jaws are closed even further down to the limit of reducing the injection efficiency.
An additional scraper with a tapered jaw was installed upstream the existing four jaw scraper to cope with incident scattering and impedance effects of the scraper. This scraper is used for active beam kill.
A new design for scrapers with appropriate shielding around is being developed.

5 SUMMARY

The analysis of the loss mechanisms lead to the conclusion that the majority of losses took place on the insertion device chambers due to limitation of the energy acceptance by the vertical integer resonance. Closing scraper jaws was found to be efficient to concentrate the losses on less critical points. Furthermore several improvements were made to reduce the amount of losses, i.e. the switch to a optimum vertical beta function in the straight sections. Measurement of the radiation level in the experimental hall, of the beam losses in the tunnel and of the activation of the vacuum vessels confirmed the suppression of the losses on the small gap vacuum vessels in the high beta straight sections. Following the success of the actions taken half of the straight sections are now operated with 11 mm inner vertical aperture vessels without problems. Furthermore several 8 mm inner vertical aperture vessels are installed now and in a test phase.

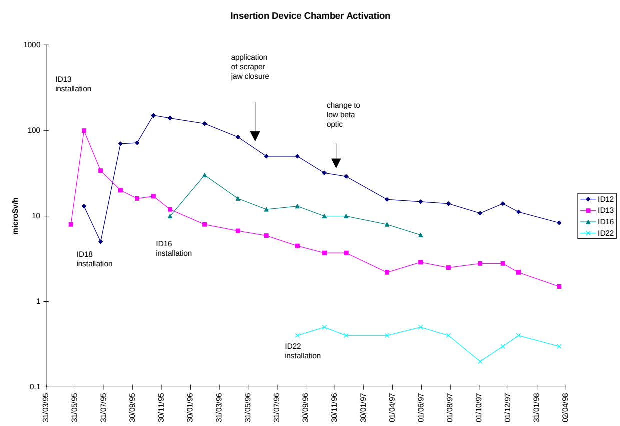

Figure 2: History of some vacuum vessel activation

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