SUMMARY OF PRESSURE RISE WORKSHOP*

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Abstract

This article summarizes the 13th ICFA Beam Dynamics Mini-Workshop *Beam-Induced Pressure Rise in Rings* (BNL, Dec. 9-12, 2003) [1].

BACKGROUND OF WORKSHOP

Beam induced pressure rise was an intensity limit at CERN ISR during the early 1970's. The beam gas ionization created pressure rise caused more gas ionization, resulting in pressure run-away at high beam intensity. Extensive baking, chamber treatment, and perhaps more importantly, a lot of added pumps helped raise the intensity threshold.

Due to the large charge exchange cross sections low energy heavy ion machines such as the AGS Booster, CERN LEAR, and GSI SIS require very high vacuum to obtain good beam lifetime. Nevertheless, the beam loss/gas ionization created pressure rise increases with beam intensity, limiting the maximum attainable intensity.

Pressure rise can also be created by electron stimulated desorption if an electron cloud has been formed by the beam. For most machines, electron cloud induced beam instability and/or beam emittance growth limit the beam intensity before pressure rise does. A special case is the RHIC, where electron clouds occur only in part of the warm sections (the total warm section is less than 1/4 of the ring). The beam intensity can be increased without inducing beam instability and emittance growth until the pressure rise impacts operation.

The beam induced pressure rise is of concern, therefore, for several machines in operation. These include the AGS Booster, the GSI SIS, and the RHIC heavy ion and proton operations.

The beam induced pressure rise is also an important issue for machines under construction or being planning. These include the LHC, SNS, LEIR, GSI upgrade, RHICII, eRHIC, and heavy ion fusion accelerators.

The Workshop focused on three aspects relevant to the beam induced pressure rise: electron and ion desorption, vacuum chamber coating and treatment, and electron cloud effects.

ELECTRON AND ION DESORPTION

The main sources of beam induced pressure rise are electron stimulated gas desorption, ion desorption, and beam loss/halo scraping [2].

For electron multipacting and ISR type ion desorption, the incident angles are typically perpendicular. Given surface conditions, electron and ion desorption rates can be obtained with reasonable accuracy.

There are, however, large uncertainties for non-perpendicular incident angle, and its importance has become apparent only recently. For example, during the design stage of the AGS Booster, the heavy ion desorption rate was believed to be between 1 and 10, and the Booster gold beam injection efficiency was designed to be high. In fact, under grazing angle the gold ion desorption rate can be larger than 10^5, and the gold beam injection loss created a pressure rise that was more than 4 decades higher than the residual gas pressure of 5×10^{-12} Torr. After more than a decade of improvements, the Booster gold beam injection efficiency is about 60% for high beam intensity.

For low-energy heavy ion machines, the beam charge exchange incidents are with the angles in the mrad range, but other beam losses may happen at even smaller angles. For high-energy machine, it is suspected that the beam loss/halo scraping may dump significant amount of energy on the chamber surface and may cause large desorption.

In recent several years, the ion desorption rate of $\sim10^5$ or higher has been observed at AGS Booster, LEAR, SIS, SPS, and RHIC. Similar results also have been obtained at several test stands. The existing data are, however, not complete and sometimes not consistent. It is not unusual that the data under similar conditions differ by orders of magnitude.

The progress and plans were discussed during this workshop. It is believed that the surface chemistry, physics and the theoretical understanding of desorption are important. For example, it is not clear yet if the bulk is involved in the desorption mechanism. It was also proposed to undertake systematic measurements with respect to projectile energy, species, charge state, and incident angle. Considering the limitations of facilities and the importance of the problem, extensive collaboration between laboratories is required.

The reduction of the ion desorption rate through beam scrubbing, i.e., heavy ion sputtering, was observed at the CERN LINAC3 test stand, and it is planned for the commissioning of LEIR. The same effect was observed at the AGS Booster over a longer time period. The other countermeasure is chamber treatment, which is the subject of next section.

CHAMBER COATING AND TREATMENT

The chamber coating and treatment are aimed at the reduction of the yields of secondary electron (SEY), secondary ion, and neutral particle from electron or ion impact [3].

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TiN coating has received much attention in the past. A general improvement of the secondary electron yield, and therefore suppression of electron multipacting, was observed, but not all times. The installation of three TiN coated chambers at the LANL PSR has yet to reach a conclusion. One of the factors might be the coating condition. For the SNS chamber coating at BNL, an improvement was recently achieved using higher sputtering pressure. The SEY was improved from 2–2.5 to 1.5–1.9. It has also been found that the better-coated TiN surface is rougher.

The newly developed NEG (non-evaporable getter) coating has been intensively discussed in this workshop. The NEG coating turns the chamber walls from an outgassing source to a getter pump, and important improvements relevant to pressure rise have been confirmed. These include the SEY reduction and electron desorption reduction. For the ion desorption, only limited measurements were done, and the results are not very consistent. One problem in measuring NEG coating ion desorption rate is that it needs to be separated from the NEG pumping. Using a saturated surface may exclude the pumping effect, but the desorption rate of non-saturated surface could be different.

An activated NEG surface has a SEY of 1.1–1.3 and, even after saturation, remains below 1.4. Some data shows higher SEY after storage, 1.3–1.6, but it is still comparable to a beam scrubbed stainless steel surface and a well conditioned TiN coating. A beam measurement at the SPS has confirmed that electron clouds are eliminated where the vacuum chambers are NEG coated.

It has been found that the roughness of the activated NEG surface improves the pumping. The SEY reduction might be also related to the roughness of the NEG surface. Test at CERN indicated that the coating surface is rougher if the chamber itself is rougher. Also, the coating process is likely to affect the roughness of the surface.

Issues relevant to the NEG coating, such as the activation, aging, possible dust, impedance, venting effect, etc. are collaboratively studied at Cornell, ESRF, GSI, KEKB, LHC, LEIR, PEPII, and RHIC.

ELECTRON CLOUD EFFECT

The mechanism of electron multipacting is in general understood, thanks to theoretical and experimental studies on electron cloud in the past years. When electron multipacting occurred in RHIC, it wasn't much of a surprise to observe the "classical" features of the electron cloud. These include the effects of bunch intensity, bunch spacing, bunch gap, solenoid field, and beam scrubbing. Also, the electron-cloud-induced pressure rise approaches saturation —rather different from the ISR type pressure rise, which rises exponentially [4].

However, many questions remain to be answered. The agreement on the electron density and distribution is yet to be reached. The relation between the electron signal and pressure rise at RHIC is not well understood. The effect of a solenoid field was not clearly identified. There are also other issues, such as dose stripes in dipole field, trapped electrons in quadrupoles, and electron bursts at the PSR.

Cures for electron clouds have been intensively pursued in recent years. Beam scrubbing has been confirmed to be beneficial at SPS and RHIC. It was found that the pressure rise induced by electron multipacting could be used as a measure for the effectiveness of the beam scrubbing. At RHIC, for example, the pressure rise was kept as high as possible to make best use of the scrubbing time.

On the other hand, it was observed at SPS that the SEY recovers after only 4 hours without running beam. The beam scrubbing study at the PSR did reduce the electron activity, but the effect on the beam instability threshold was not clearly identified.

A challenge for LHC and eRHIC is that the recent measurement at the SPS shows that in terms of electron activity and heat load the beam scrubbing is less effective at the cold regions. The beam instabilities and the tolerable heat load during scrubbing also need to be considered.

The outlook for the application of NEG coating is generally encouraging with respect to pumping and SEY reduction. In addition to measurements in test chambers, the machine experiences at SPS, ESRF, Cornell, and recently the RHIC are mostly positive.

Several other techniques to prevent the electron clouds are also effective depending on the machine operations and limitations. Solenoids play a key role in raising luminosity at the B-factories. Colliders can adopt flexible bunch injection pattern to maximize the luminosity. For example, the bunch filling pattern is adjustable during RHIC operation, depending on pressure rise limits. In general, it is better to extend the bunch spacing and to raise bunch intensity. At RHIC, the 56-bunch pattern yielded less background and higher luminosity than the 112-bunch pattern used in the past. The electron multipacting threshold at SPS shows that for 25 ns, 50 ns, and 75 ns bunch spacing, the bunch intensity thresholds are $0.3\text{x}10^{11}$, $0.6\text{x}10^{11}$, and $1.2\text{x}10^{11}$, respectively. The corresponding luminosity ratio would be 1, 2, and 5.3, given that the luminosity is proportional to square of bunch intensity.

CONCLUSION

Many new results reported at this workshop were obtained during the last few months, not years, indicating the interest and need of existing and planned machines.

With the constant improvement in accelerator technology and pursuit of high intensity and luminosity, many machines are now facing limits caused by particles other than the beam. Electron clouds are a typical example, but ions are also relevant, especially in hadron machines. The direct and indirect effect of these ions may not be negligible.

Ions involved in RHIC pressure rise include: beam gas ionization generated ions, beam loss generated ions,

secondary ions due to these two kinds of ions, and secondary ions generated from electron multipacting. Electrons in the beam pipe are promptly kicked to the wall by each passing bunch. Ions are also pushed to the wall by the circulating beam. The lifetime of secondary electrons in the gap between bunches could be affected by these slow moving ions.

It is very important to identify and understand the dominant mechanism in each type of pressure rise. This goal is served by the several fronts pushed forward during this workshop, i.e., the understanding of the electron and ion desorption, the chamber coating and treatment, and the comprehensive strategy to prevent electron clouds during the accelerator and collider operations.

REFERENCES

[1] http://www.c-ad.bnl.gov/icfa/

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