# BEAM LOSS DIAGNOSTICS BASED ON PRESSURE MEASUREMENTS

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*Abstract*

The GSI is operating a heavy ion synchrotron, which is currently undergoing an upgrade towards higher beam intensities. It was discovered that beam losses induce a significant pressure increase in the vacuum system. This effect can be used as beam loss diagnostics. In addition fast total pressure measurements were put into operation in order to detect the time constants of the pressure increase and decrease.

## 1 Measurement Principle

The energy loss per unit length of ions in matter depends on the kind, energy and charge state of the ions as well as on the target material. For heavy ions this energy deposition might be so high that effects like sputtering, melting, crack formation, etc. might occur. During such impacts a lot of gas molecules are released. The desorption yield, i.e. the number of gas molecules released per impact ion has been reported to be in the range from $10^3$ to $10^5$. This effect has been studied at CERN [1] and is object to further investigations at GSI [2]. The typical value measured for the stainless steel vacuum chamber of the GSI heavy ion synchrotron SIS is $10^4$.

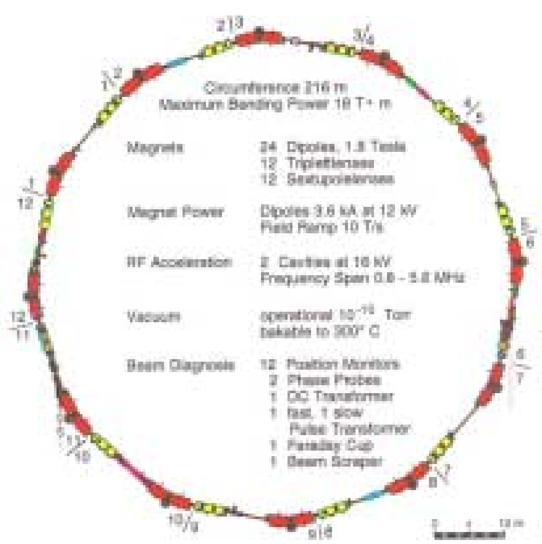


**Fig. 1:** The GSI heavy synchrotron SIS

The release of gas molecules increases the pressure in the vacuum system of the accelerator. The measurement of the pressure rise with pressure gauges contains the information about the amount of the lost ions as well as their impact point on the vacuum chamber. In the SIS the total pressure measurement is done with 12 IE514 extractor gauges from Leybold equally distributed around the ring. These gauges can reliably measure down to a few $10^{-12}$ mbar. The distance between two gauges is 18 m.

The pressure rise due to ion losses is immediate. There is also a typical pumping down time, which depends on the kind of gas molecules and the pumping system. In the SIS this pumping down time is the range from 10 ms to 10 s.

It is important to mention two cases: a constant loss rate and single loss events. One can consider a constant loss rate when the rate at which the losses take place is shorter than the pumping down time. In this case the pressure will increase to a kind of dynamic equilibrium. In the SIS this is the case for chemically inert gases in combination with short cycle times of the synchrotron. For the case of long cycling times and/or chemically active gases the released gas molecules are pumped away before the next significant ion loss appears.

## 2 Average total pressure and lifetime

Heavy ion circular accelerators operate at low pressure. The base pressure for the SIS for example is around $2\cdot10^{-11}$ mbar. This corresponds to about a total of $2\cdot10^{12}$ free gas molecules in the vacuum system. With the above mentioned desorption coefficient the amount of ions necessary to create a total pressure rise equivalent to the base pressure of the SIS can be estimated to about $2\cdot10^8$. If this amount of ions is lost in a short time the lifetime decreases by a factor of two. This is therefore about the detection limit for beam losses just from total average pressure or lifetime. The value of $2\cdot10^8$ ions accelerated is close to the operation value for $U^{28+}$. Measurements of the total pressure and beam lifetime as function of the loss rate were done and are summarised in the following tables:

| Beam type | Loss rate [$10^7$ions/s] | Pressure [$10^{-11}$ mbar] | Lifetime [s] |
|---|---|---|---|
| no beam | | 1.96 | |
| $U^{28+}$ | 1.2 | 2.13 | 5.0 |
| $U^{28+}$ | 11.4 | 2.62 | 3.6 |
| $U^{73+}$ | 0.88 | 1.99 | 14.4 |
| $U^{73+}$ | 1.6 | 2.03 | 12.4 |
| $U^{73+}$ | 2.2 | 2.22 | 12.3 |

**Tab. 1:** total pressure and lifetime as function of loss rate

| Ion species | $U^{28+}$ | $U^{73+}$ |
|---|---|---|
| Pressure increase [mbar/ions/s] | $9.9\ 10^{-20} \pm 41\%$ | $7.2\ 10^{-20} \pm 63\%$ |
| Pressure · lifetime [s · mbar] | $1.0\ 10^{-10} \pm 6\%$ | $2.7\ 10^{-10} \pm 6\%$ |

**Tab. 2:** lifetime as function of pressure and pressure increase as function of loss rate

There is a program to further increase the intensity for uranium operation by about three orders of magnitude up to $2 \cdot 10^{11}$ ions per cycle. The beam loss induced pressure rise has therefore to be drastically reduced by means of total beam loss reduction, reduced desorption coefficient and increased pumping speed.
In order to reach this goal the detection of beam losses, partial and total pressure is currently improved in order to provide efficient diagnostic for machine optimisation.

## 3 Localised losses

Losses are in general not equally distributed around the ring. If for example the losses are localised to a single point in the vacuum system, the pressure rise also occurs locally. In this case the detection of the local pressure rise is possible even without a significant impact on the lifetime. During different measurements it was found that a local pressure rise is reduced by about one order of magnitude over the length of one sector, i.e. about 18 m. This is due to the limited conductance of the vacuum chamber in combination with the pumping stations in the sector. As the SIS contains 12 sectors one can say that a local pressure rise extends over 1/12 of the ring. The detection limit for local losses from the pressure rise is therefore about one order of magnitude lower than for the average pressure. This means that already losses of a few $10^7$ ions can be detected. This was indeed proven by measurements. It has to be mentioned here that the distribution of the base pressure around the ring is far from being uniform. Consequently the detection limit for local losses also varies from extractor gauge to extractor gauge.
With a detection limit of a few $10^7$ lost ions it is possible to follow up the operation settings for high intensity heavy ion operation and to optimise the settings with it.

## 4 Time dependence of pressure

In the $10^{-11}$ mbar pressure range the collected ion current on the extractor gauges is very low. The standard treatment with the IM520 control unit is too slow to provide sufficient time resolution for the follow up of the pressure increase and decrease after an ion impact. Therefore a fast current to frequency converter was used to measure this dynamic. The basic parameters of this electronic are:

- Sensitivity of 1pC/pulse
- Pulse width of 50ns
- A dynamic range of 7 decades
- A maximum output frequency of 10 MHz
- Linearity of 0.1% below 1 MHz and 3% between 1 MHz and 10 MHz
- TTL 50 Ohm output

In figure 2 the electronic layout is shown.

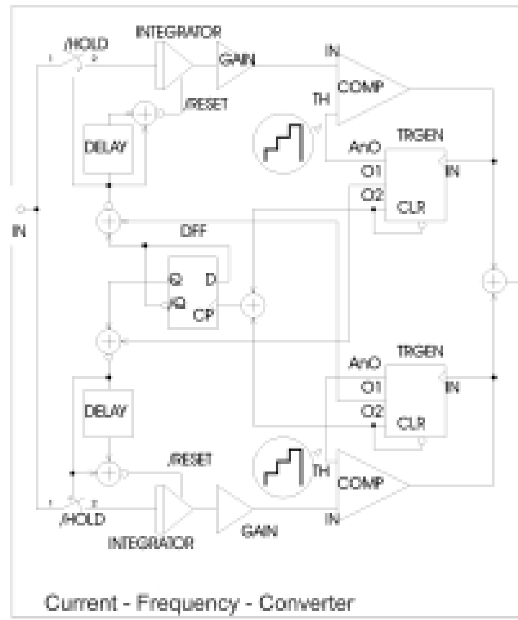


**Fig. 2:** Electronic for the fast pressure measurement

In figure 3 the electronic output is shown for three extractor gauges during a slow beam loss induced pressure increase. The total time scale is 100 s.

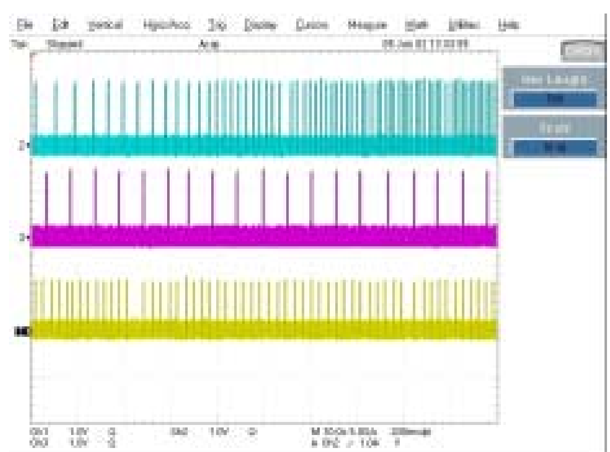

**Fig. 3:** Output of the fast pressure measurement during a pressure increase.

The time resolution of the measurement is given by the time that the extractor gauges need to accumulate 1pC ion current. At $10^{-11}$ mbar this time is about one second. It is therefore possible to follow up a dynamic pressure increase for pumping down times in the range for 10 seconds even down to the $10^{-12}$ mbar range. In order to measure in the 100 ms range, on the other hand, a pressure increase of at least $10^{-10}$ mbar is required. In this respect it has to be mentioned that seven fast residual gas analysers are installed around the ring. In principle they yield the potential to follow up the evolution of a specific gas molecule with a time resolution better than one second. This potential will be exploited in the near future.

## 5 Potential of the method and outlook

At the GSI pressure measurements provide beam loss diagnostics for some important operation modes.
As the vacuum system is closed all released gas molecules stay within the detection volume. This eases the positioning of this diagnostics.
Another advantage is that for vacuum reasons this diagnostic is anyhow installed. Therefore the investment and operation costs remain low.
As the beam loss induced desorption is a major issue for the operation of high intensity heavy ion accelerators this diagnostic is ideal to overcome this obstacle.
The main disadvantage of this method is that it can only be used at high intensity heavy ion accelerators.

At GSI this diagnostic was made operational mainly for vacuum reasons. The task of full integration into the machine control system has still to be provided to be fully operational as optimisation tool. The next step will be the exploitation of the residual gas analyser network. With this system it is possible to follow up the evolution of different gas species. There is a hope to identify a gas species which is strongly released from the chamber wall but not so present in the base pressure. This will provide an improved signal to noise ratio. If one only sticks to one mass the time resolution of the RGAs is in the subsecond range so that also the dynamics of the pressure can be studied.

## References

[1] Ion-stimulated gas desorption yields and their dependence on the surface preparation of stainless steel, E.Mahner, J.Hansen, D.Küchler, M.Malabaila, M.Taborelli, EPAC2002, Paris

[2] Measurement and Calculation of U28+ beam lifetime in SIS18, A.Krämer, O.Boine-Frankenheim, E.Mustafin, H.Reich-Sprenger, P.Spiller, EPAC2002, Paris