PROGRESS TOWARDS HIGH INTENSITY HEAVY ION BEAMS AT THE AGOR-FACILITY*

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Abstract

The AGOR-facility has an on-going upgrade program aiming at intensities beyond 10^{12} pps for heavy ion beams up to Pb. The main elements of the program are: further development of the ECR-source, improvement of the transmission into and through the cyclotron, and protection of equipment against excessive beam loss. Further improvement of the ECR ion source is facilitated by the installation of a second source. Redesign of the Low Energy Beam-line, to compensate for aberrations, is in progress; simulations predict a significant increase in transmission. A new, cooled, electrostatic extractor is being commissioned and the beam loss control system has been completed. The main remaining issue is vacuum degradation induced by beam loss caused by charge exchange on the residual gas. Tracking calculations of the distribution of the beam losses over the vacuum chamber to determine the optimum location of scrapers are underway. A gold coating was recently applied to relevant parts of the vacuum chamber aiming at reduction of beam loss induced desorption.

INTRODUCTION

The AGOR-facility delivers heavy ions beams up to Pb for experiments in the framework of the TRIμP programme on fundamental symmetries.

Experiments on violation of time reversal symmetry in β-decay are performed with beams up to ^{40}Ar at energies between 20 and 30 MeV per nucleon. The objective for the beam intensity during the final production runs of these experiments is around 10^{13} pps, corresponding to a beam power of around 1 kW. Currently the beam intensity for these experiments is limited to 4×10^{12} pps (300 W) by constraints in the experimental setup. During test experiments we have achieved an extracted beam intensity of 1.3×10^{13} pps for a $^{20}Ne^{6+}$ beam at 23.5 MeV per nucleon, corresponding to 1 kW beam power.

For experiments on permanent electric dipole moments and atomic parity violation in Ra-atoms and –ions, beams of various Pb-isotopes with an energy in the range 7 – 10 MeV per nucleon are used. In the on-going development phase of these experiments beams with an intensity up to 3×10^{11} pps (100 W) have been delivered. For the production phase of these experiments we aim at a beam intensity exceeding 10^{12} pps. In this paper we describe the on-going improvements, in several areas that directly or indirectly limit the beam intensity for these beams, which are needed to achieve this goal.

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ION SOURCES AND LEBT

Following the phasing out of the experimental programme with polarized proton en deuteron beams the polarized ion source POLIS was decommissioned. The source and the associated Lamb shift polarimeter have been transferred to PNPI, Gatchina for experiments in low energy nuclear physics. At the location of POLIS we have now installed a 14 GHz Supernanogan ECR source that we have obtained on a long term loan from HZB, Berlin. The source will be used to produce the beams of gaseous compounds, while the 14GHz AECR-source will be dedicated to the production of metal beams.

The performance of the 14 GHz AECR-source has been significantly improved during the last years by a number of modifications that are elaborated in ref. 1. We now routinely produce 50 μA of Pb^{27+} beams and more than 500 μA of $^{16}O^{6+}$ and $^{20}Ne^{6+}$.

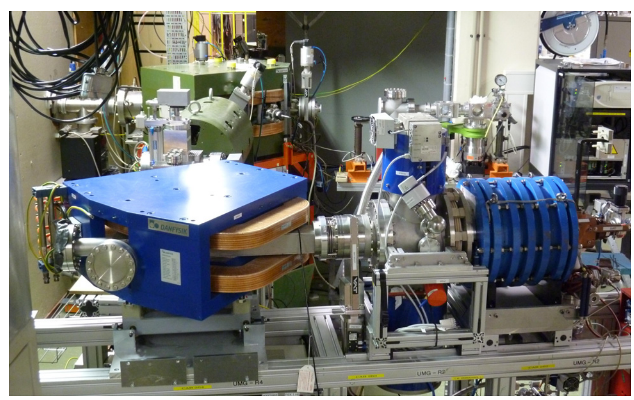

Figure 1: Supernanogan ECR source and beam line.

In the 20 m long beam transport line between the ECR ion sources and the cyclotron up to 50 % of the beam is lost. Detailed simulations and emittance measurements show that these are mainly due to the aberrations in the various magnets, which lead to an increase of the apparent emittance [2]. The beam line is currently being redesigned on the basis of these findings. The redesign of analyzing magnet of the AECR-source, similar to that developed at LBNL [3] has been completed; production of the new magnet poles is about to start.

For the Pb^{27+} beams losses in the low energy beam line due to charge exchange are non-negligible. In the horizontal part of the beam line the vacuum was improved to 3×10^{-8} mbar by baking the components and removing some parts with high outgassing. In the 5 m long vertical beam line into the cyclotron the vacuum is in the 10^{-7} mbar range due to lack of pumping speed. The high stray fields preclude the use of turbomolecular pumps and cold heads. We are investigating the possibilities to install NEG-pumps [4] to improve the vacuum and thereby the transmission for the Pb beams.

The AGOR-cyclotron is equipped with a single harmonic sinusoidal buncher at 0.5 m from the median plane. A bunching efficiency of 35 % has been deduced from measurements using the phase probes [5] and from the gain in intensity obtained with the buncher. A substantially higher bunching efficiency can be achieved with a multi-harmonic bunching system. We are currently working on the conceptual design of a new buncher system, preferably including the existing buncher.

VACUUM DYNAMICS

The desorption caused by beam particles impinging on the walls of the acceleration chamber and the acceleration electrodes after a charge changing collision with the residual gas leads to a degradation of the vacuum and thereby to an increase in the losses [6, 7]. Due to this mechanism the extracted beam intensity for heavy ion beams exhibits a maximum as a function of the injected intensity: injecting a higher intensity results in a lower extracted current. The actual value of the maximum intensity strongly depends on ion species and final energy. For heavy ion beams up to Ar with energies above 20 MeV per nucleon a degradation of the vacuum and consequently the transmission has been observed but the intensities requested for the experiments can be delivered. For the Pb-beams in the energy range 7 – 10 MeV per nucleon operational experience and calculations show that the maximum achievable intensity is below the value requested for the experiments.

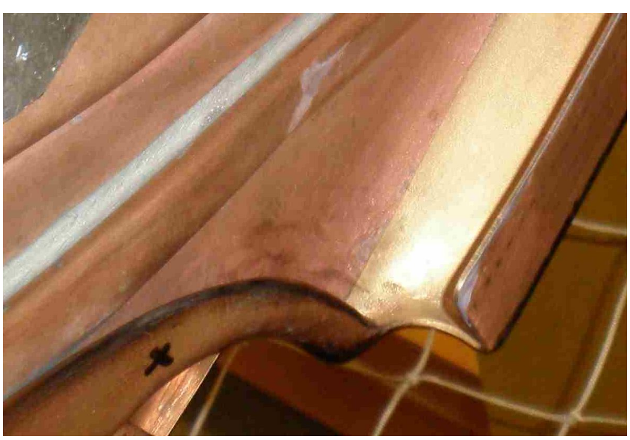

Figure 2: Detail of the gold coated outer perimeter of the acceleration electrodes.

The pumping speed in the acceleration chamber is due to the 18 mm height of the acceleration chamber conductance limited even with the internal cryopumps in use. Improvement of the beam transmission can thus only be achieved by reducing the desorption. On the basis of the work described in ref. 6 we applied a gold coating to the outside perimeter of the acceleration region. This is expected to reduce the local high energy beam loss induced outgassing by a factor 10.

UV-stimulated outgassing, improved cleaning procedures and the additional pumping speed of a third internal cryopump will further reduce both the base pressure and the desorption yield, thus enabling higher beam intensities.

EXTRACTION SYSTEM

The extraction efficiency for the relevant heavy beams from the AGOR cyclotron typically exceeds 85 % and has been found to depend only weakly on the beam intensity. The beam losses occur mainly in the electrostatic deflector, with minor losses in the subsequent electromagnetic channels.

The losses in the second, superconducting channel do not lead to quenching as the (relatively low energy) particles are stopped in the inner 20 K-shield of the channel. The temperature increase of the shield has turned out to be a useful diagnostic to optimize the transmission through the channel. Minimizing the beam losses in the channel is also important because of the important outgassing from the cold surface they induce.

The original electrostatic deflector is not actively cooled. With a septum with a V-groove at the entrance it has operated very reliably for the intensities delivered up to now. For the operation at the higher intensities anticipated for the production phase of the experiments, an upgraded electro-static deflector with cooling has been developed, which is currently being completed and will be installed in the cyclotron at the end of 2010.

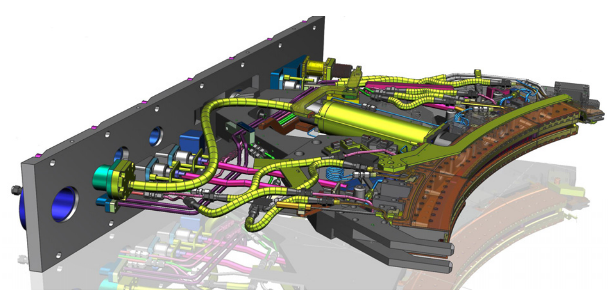

Figure 3: New electrostatic deflector

The tungsten septum has a V-groove to spread beam losses and is cooled via a cooling circuit in the upper part of its support structure. Geometrical constraints prevented the lower part to be cooled as well. In order to reduce beam losses on the septum even further a tungsten pre-septum with V-groove has been installed up stream of the septum as part of the collimator at the entrance of the deflector, which is shown in fig. 4.

The cathode is cooled via conduction through the aluminium nitride insulators, which are internally water cooled at the ground side. Extensive testing showed that the new insulators reliably operate at voltages up to at least 60 kV, while the maximum voltage required is 46 kV. Breakage of insulators due to stresses introduced by the brazing of their titanium endcaps was remedied by minor modifications of the brazing procedure.

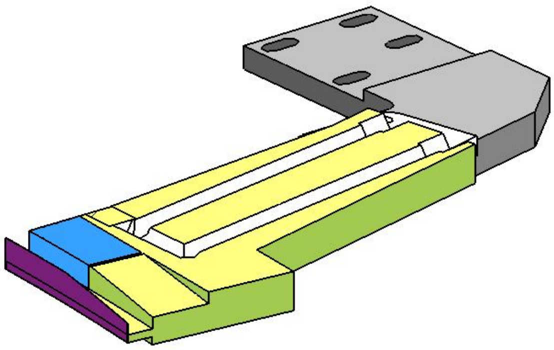

Figure 4: Cross section of the pre-septum of the electrostatic inflector. Violet: 0.2 mm tungsten foil; blue: tungsten block to stop protons; green/yellow: copper block with direct water cooling

BEAM LOSS CONTROL

Beam losses in the extraction system and high energy beam line cause power densities up to 1 kW/mm^3 in the materials in which the beam is stopped. Such power densities result in damage to components at the 10 – 100 ms timescale. Therefore a system for fast beam loss monitoring and control is essential for safe operation. We have developed and commissioned such a system based on previous developments at GANIL [8] and GSI [9]. It is described in more detail elsewhere in these proceedings [10]; here we only mention the main characteristics.

The beam losses in the cyclotron and high energy beam line to the entrance of the fragment separator (split up in six sections) are assessed by measuring the beam intensity at the entrance and exit of each section with non-destructive inductive pick-ups and the localized losses on collimators and slits. The non-localized losses in each section are determined from a current balance. Localized or non-localized losses in the cyclotron or any section of the high energy beam line exceeding an individual preset limit cause the duty cycle of a chopper in the injection beam line to be reduced stepwise until the losses are again within safe limits. Losses exceeding a second, higher limit, typically related to error conditions, cause the beam to be interrupted within 10 ms.

Increasing the duty cycle of the chopper or switching the beam on again after remedying the cause of the too high losses requires operator intervention.

The system also protects the semi-interceptive beam profilers. Inserting a beam profiler under normal operating conditions causes the beam to be interrupted. After inserting a pepperpot in the injection line to reduce the primary beam intensity to a safe level the operator can switch the beam on again.

CONCLUSION

We have demonstrated that the AGOR cyclotron can deliver beams with an intensity exceeding 10^{13} pps for elements up to Ar accelerated to an energy in the range 20 – 30 MeV per nucleon. The beam loss monitoring and control system needed for safe operation has been completed and the new electrostatic deflector that can withstand such beams for long periods is nearly completed.

For the heavy elements such as lead, the maximum obtained beam intensity of 3×10^{11} pps is due to limitations related to ion optics, injection efficiency and vacuum. The obtained intensity is still a factor three below the ultimate requirements for the experiments. With the on-going improvements on all these aspects the requested intensity is well within reach.

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