AGOR STATUS REPORT

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Abstract

The AGOR-facility is now operating reliably with an availability approaching 90%. Past problems with beam transmission for high energy protons have been cured by repositioning the main coils. In conjunction with a fundamental physics programme requiring high intensity beams of heavy ions up to lead several development activities have been started.

FACILITY OPERATION

In the period 2001 - 2004 the AGOR facility has delivered on average 3000 hours of beam for experiments per year. Beam tuning required around 350 hours per year and unscheduled maintenance nearly 500 hours per year. Mains failures, occurring on average twice a year, are the most important source of downtime, accounting for some 30 % of the lost time. The availability of the facility is approaching 90 %, which is our target.

During the last two years the operating of the facility was limited to 26 weeks to allow the extensive building and installation activities for the dual-mode TRIμP separator [1]. The commissioning of the fragmentation mode has been successfully completed; currently the fusion mode is being commissioned using Pb-beams.

VERTICAL BEAM DYNAMICS

Despite the careful vertical alignment of the main coils [2] internal beam losses due to large coherent vertical motion of the beam have been observed for the highest energy (190 MeV) proton beam. These losses were not observed for other beams as close to the focussing limit as the proton beam. The localisation of the losses at radii where the coupling resonance ν_r-ν_z = 1 occurs and the absence of this resonance for the other beams lead to the conclusion [3] that this resonance might be responsible for the beam losses.

Measurements of the vertical beam position as a function of radius for the 190 MeV proton beam and a number of proton and deuteron beams at other energies showed a similar coherent vertical motion pattern for all beams. The amplitude of the vertical motion becomes larger the closer the beam energy is to the focussing limit [4]. From these measurements it was concluded that a vertical alignment error of about 0.5 mm exists between the main coils and the iron. This conclusion has been confirmed by vertical beam position measurements made after changing the coil position by -0.34 mm and by the disappearance of the internal beam losses.

A substantial coherent vertical beam motion subsists, indicating that the symmetry planes of the iron and the coils do not yet coincide. Magnetic measurements with a new version of the probe measuring the radial field component are being planned to gain more insight and to allow further corrections.

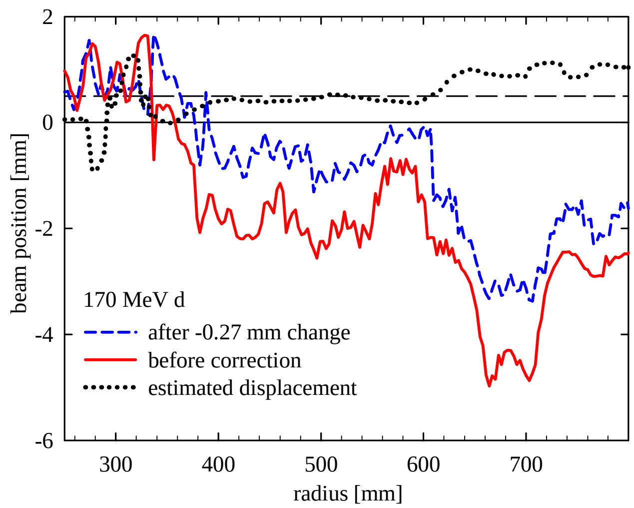

Figure 1: Vertical beam position for 170 MeV deuterons before and after correction of the main coil position (full and dashed curves). The dotted curve represents the initial displacement of the main coils derived at each radius from the difference between the two measurements

EXTRACTION

Since the beginning of the regular operation of the AGOR-facility in 1996 the maximum magnetic field has been limited to 3.5 T because of pinching of the electro-magnetic extraction channel EMC1 between the magnet poles. This is caused by the channel being higher than designed because of insulation material inserted to cure ground faults and by a larger compression of the magnet poles at high fields than predicted. A new, lower extraction channel, allowing the field to be increased to the nominal 4.1 T, has been completed in 2003 and commissioned successfully in 2004. However, after several months of operation the new channel, in which ceramic insulation of the windings has been used, has recently developed ground faults. This has forced us to resort to the original channel. The cause of the ground faults has not yet been identified.

DIAGNOSTICS

Strong perturbation of the signals on the phase probes by the RF-resonators, not only at the fundamental but also at higher harmonics, makes it impossible to perform beam-phase measurements over the full operating range at the second harmonic of the RF-frequency. The phase information can be transferred to a frequency where no perturbation from the RF-resonators is present by intensity modulation of the injected beam. We have now developed a system suitable for routine use by the operator [5]. By slightly changing the buncher frequency f_{bun} with respect to the RF frequency f_{RF} intensity modulation at $f_{mod} = f_{RF} - f_{bun}$ is produced. The phase information is extracted at the frequency $2f_{RF} – f_{mod} = f_{RF} + f_{bun}$. The reference signal is conveniently produced by mixing signals from the buncher and a RF-resonator. A statistical accuracy of 1° at a beam intensity of 10 nA is achieved over the full operating range.

VACUUM UPGRADE

In the design of the AGOR-cyclotron three cryogenic pumps [6], installed in the upper half of the RF-cavities, were foreseen. During the commissioning of the pumps a number of design flaws were found, which required them to be substantially modified. The rebuilt and extensively tested pumps have been installed again in the cyclotron and have been successfully operated for long periods over the past year. With all three pumps operating a vacuum of 4 x 10^{-7} mbar can be achieved, four times better than obtained with the two turbo-molecular pumps and the cryogenic extraction channels.

High-intensity operation

At a pressure of 4 x 10^{-7} mbar the transmission of $^{208}Pb^{27+}$, $^{131}Xe^{17+}$ and $^{15}N^{2+}$ beams accelerated to 8 MeV per nucleon is well above 90 % for low intensities. However, during initial tests with a high intensity $^{15}N^{2+}$ beam at a base pressure of 10^{-6} mbar an intensity dependent degradation of the vacuum and consequently of the transmission has been observed. With an intensity of 10^{13} pps (particles per second) at small radius the vacuum degraded to 10^{-5} mbar in a few minutes, resulting in a transmission decreasing to less than 10%. This is explained by processes induced by ions and electrons impinging on the walls after charge changing collisions, resulting in a desorption yield of up to 10^6 atoms per lost ion [7].

From a very simple model, which neglects the energy dependence of the loss cross section and the desorption yield (see fig. 2) we conclude that our observations can be explained with a desorption yield of about 10^5. The key factor in solving this problem is to reduce the quantity of absorbed gas on the walls. This will improve the base pressure and the desorption yield.

ION SOURCE DEVELOPMENT

ECR heavy ion source

To meet the intensity requirements of the future experiments in fundamental physics and in particular of the Ra-EDM experiment we have started work on metallic ion beams [8] and an upgrade of the ECR heavy ion source [9].

The work on metallic beams has concentrated on Mg and Pb. The material is brought into the plasma by evaporation from an oven. For the Mg-beams a thermally floating Ta-screen has been installed in the plasma chamber, which significantly increases the intensity and the ‘pot-life’ of the Mg in the oven. A maximum intensity of 5 μA has been obtained for $^{208}Pb^{27+}$. Beams of $^{24}Mg^{10+}$ and $^{207}Pb^{27+}$ have been successfully accelerated and used for experiments.

In the first stage of the upgrade the permanent magnet hexapole and the plasma-chamber with ancillaries are replaced by components based on the LBNL AECR design [10]. With the new source and an improved low-energy beam transport it should become possible to deliver beam intensities on target up to 10^{12} pps. In a later stage a further upgrade by installing high-T_c super-conducting coils (*cf.* the Grenoble PHOENIX-design [11]) is anticipated in order to increase the beam intensity to 10^{13} pps.

Polarised ion source

The polarised ion source at the AGOR-facility has been equipped with a Lamb-shift polarimeter (LSP) [12]. In this way the source parameters can be optimised off-line before the experiments, rather than using the accelerated beam. The LSP directly measures the relative population of the magnetic sub-states in the beam and is, in contrast to polarimeters based on the measurement of yield asymmetries, insensitive to systematic errors. It provides a polarisation measurement with 1% statistical accuracy every 30 s. The use of the LSP has resulted in higher polarisation than previously achieved: 92% for protons and 80% for deuterons (both vector- and tensor-polarisation). For deuterons the admixture vector-polarisation in a tensor-polarised beam and vice-versa critically depends on tuning the efficiency of the two transition units that are used in series. With the LSP it has been possible to reduce the admixture to the 1% level.

Comparison of the polarisation in the low-energy beam and in the accelerated beam, measured with the in-beam polarimeter [13], indicates a polarisation loss during acceleration of about 15% for 190 MeV protons. This might be caused by the large coherent vertical motion observed for this beam. Measurements on other beams, to establish a possible correlation between the polarisation loss and the vertical motion, and a crosscheck of the LSP-results using the analysing power of the $d(d, n)^3He$-reaction at low energy are under way.

Low-energy beam transport

The transmission of heavy ion beams from the ECR source to the injection point in the cyclotron was generally around 10%. The losses are localised in a relatively long section without focussing elements, where the beam line from the ECR source is merged with the beam line from the light ion source. New optics calculations and measurements have resulted in an increase to 25%, which is still unsatisfactory but sufficient for the experiments currently being performed.

For the future experiments with high intensity heavy ion beams a transmission of essentially 100% is needed. The calculations show that this can only be achieved with a major redesign including relocation of the light ion source.

FUTURE DEVELOPMENTS

In the coming years the emphasis in the experimental programme at the AGOR-facility will shift from nuclear structure and few body physics with light ion beams towards fundamental physics using heavy ion beams to produce radioactive nuclides. The intensities aimed at (ultimately up to 10^{13} pps) do not only require substantial development work on the ion source and vacuum, discussed above, but also a new electrostatic deflector, additional diagnostics and a new approach for radiation and equipment safety in relation to beam losses. First exploratory work on these issues has started.

ACKNOWLEDGEMENT

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