IMPROVING THE ENERGY EFFICIENCY, RELIABILITY AND PERFORMANCE OF AGOR*

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Abstract

Over the past few years the nature of the experiments performed with AGOR has changed from long experiments, to sequences of short experiments, often using different beams. In addition the total demand for beamtime has gone down. This has required a change in operating procedures and scheduling. In view of the changing demands, we are continuing our efforts to improve the energy efficiency and reliability of the cyclotron, while at the same time trying to improve performance. While some of the solutions might be unique to our facility, many will have broader applicability.

HISTORY

- In 1996 a new K600 superconducting cyclotron, AGOR, was installed in Groningen
- In 2003 a new separator was built for the TRIμP program.
- In 2005 a Noctua monitoring system for the electrical power consumption was installed, and expanded in 2007
- Since 2005 the European space agency ESA uses the irradiation facility for radiation hardness testing.
- In 2006 the Irradiation beam line (H-line) was moved from the west to the east side of the building.
- In 2007 a SUPERNANOGAN ECR source was obtained on loan from the Helmholtz Zentrum Berlin (HZB), Germany.
- In the 2007/2008 winter maintenance period a heat recovery system was installed on the big cryo-compressor.
- In 2012 the power distribution system of the building was completely replaced.

BEAMTIME AND USERS

At the time of construction AGOR was intended to provide both polarised light ion beams as well as heavy ion beams. During the initial years several nuclear physics programs were executed with experiments of, usually low intensity, (polarised) light ion beams and typically multi day duration.

In 2003, because of the TRIμP program, requirements changed to high intensity low energy heavy ion beams. Due to the complexity of these experiments the beam development and tuning time required became much longer and experiments eventually took up to two weeks, including the weekends. The TRIμP program will end on 31st of December 2013.

Meanwhile a new category of, partly commercial, users has appeared, using the cyclotron for radiation hardness testing and radiobiology. The available 190 MeV proton beam is well suited for simulating solar flares. The 150 MeV proton and 90 MeV/amu carbon beams are excellent for radiobiology experiments. These experiments are typically short in duration, with a large variety in desired beam intensities and energies. The latter often can be provided from a single high energy primary beam with the use of an automated degrader in the irradiation experimental area.

In 2002 more than 3000 hours of beam were provided to our users for nuclear (astro-)physics experiments with the Big Byte Spectrometer (BBS) and other beamlines, and less than 100 hours for experiments with the multi user facility (2 irradiation experiments). In addition 700 hours of unscheduled maintenance were used, mainly for issues with the cryogenic system [1].

In 2012 a total of nearly 1300 hours of beamtime were provided to our users, distributed over 4 TRIμP experiments (total 490 hours), a long experiment with the BBS (234 hours) and 15 irradiations (326 hours, including one irradiation of 193 hours). In 2012 a little over 200 hours of unscheduled maintenance were needed, mainly due to water leaks in the cyclotron.

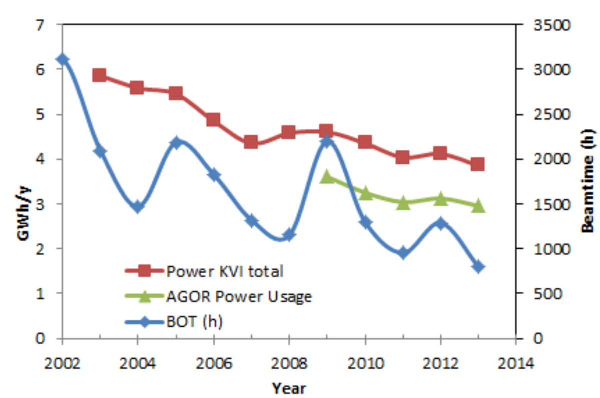

Figure 1: Annual Electrical Energy Usage, AGOR fraction and Total Beam time (hours, right axis). The value for 2013 is a conservative estimate.

SUBSYTEMS

Even though subsystems are discussed separately in the following section, modifications to one subsystem often affect several others.

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Vacuum

Many of the roughing pumps along the beamlines were old and have been replaced with modern more efficient pumps. In addition a new regime was introduced where beamlines not in use are closed off and pumps turned off. Under normal operating conditions the pump capacity on the beamlines and cyclotron vacuum chamber is much higher than needed. During normal operation turbopumps share roughing pumps, and the full capacity is only used during pumpdown (beamlines and cyclotron) and warmup of the cryostatic elements or cryopumps (cyclotron vacuum chamber). The cryopumps on the cyclotron are rarely used, since the losses due to vacuum are very low for the high energy light ion beams commonly used for irradiations.

RF

A critical look at the RF amplifiers resulted in lower grid voltages with the same power output, reducing the required electrical power needed.

Operating procedures were adjusted, where RF power is turned off whenever feasible and conditioning times for several beams were reduced by a minor change in procedure.

Cryogenics

Thanks to a major overhaul of the cryogenic control system [2] a more economic operation of the helium compressors is now possible, where the cooling power provided is automatically adjusted. During extended periods of downtime, of two weeks or more, the main coils are no longer cooled with liquid He but kept cool with cold He-gas. This requires much less cooling power from the cryosplant and thus considerable less power. Before startup the main coils and extraction elements are returned to operating temperatures in a mostly automated procedure, typically done over the weekend preceding operations.

The changes to the operating system and procedures have also made the system much less susceptible to power outages. The main remaining issue now is the fact that the very rare (~once per year) power outages of more than a few seconds disable our use of the control system. Solutions to this issue are under consideration but will require a substantial expansion of our emergency power system.

A remaining issue is our inability to turn off the small compressor without possibly causing damage to the coalescing filters. This issue is under investigation but might require hardware changes. Ideally the small compressor is turned off during periods of downtime.

Extraction

The first electromagnetic channel, EMC-1, has been replicated with slight modifications to enable us to reach full magnetic field. In the past years several water leaks occurred, both in the old version, as well as in the new one. Recently a new bias coil was built, we expect this to provide leak free operations during the remainder of AGOR's lifespan.

The second (superconducting) electromagnetic channel, EMC-2, is warmed up whenever possible since it requires relatively large cryogenic cooling power. The last cryogenic extraction element, Q-pole, is warmed up during extended periods of downtime.

New tunes with lower currents and voltages in the extraction elements have improved reliability and probably reduced wear as well as power usage.

Injection and Ion sources

With heavy ion beams a considerable fraction of the beam was lost due to poor vacuum conditions in the injection line. There is very little opportunity to increase the pump capacity in this area, but a periodic baking out of the beamline improved operating conditions and source to injection transport efficiency [3].

The SUPERNANOGAN source on loan from HZB consumes much less electrical power than the AECR, an added benefit of the availability of this source for 'easy' heavy ion beams.

Cooling, Heating and Compressed Air

The temperature regime in the accelerator hall was adjusted from 21 °C to 16 °C. The ventilation, and lighting, of the hall is also turned off when not needed, providing additional savings without affecting the equipment.

An unexpected negative side effect of this new temperature regime was reduced temperatures in the adjacent experimental areas. This was countered by introducing local heating in the irradiation area obtained from a heat exchanger using waste heat of the small compressor.

In the Netherlands central heating is gas powered. With the introduction of a heat-exchanger between the helium compressors and the building heating system [4], not only was the gas consumption for heating of the building greatly reduced, but the required cooling power of the cooling towers as well, providing a win-win scenario.

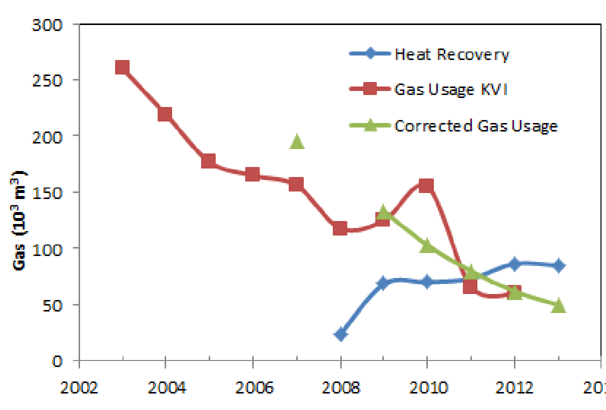

Figure 2: Annual gas consumption. The green line is measured values corrected for average temperatures over 2002-2010, removing the effects of annual variability.

The cooling towers capacity was dimensioned for a larger need and the system is not as flexible as we would have liked. We are currently working on changing the way systems are cooled during downtime, with the goal to only use a single cooling tower during these periods

The compressed air system in the experimental areas was checked for leaks this summer, resulting in a reduced load on the compressed air system. Continued vigilance is needed to prevent the recurrence of small leaks.

Power Supplies

Most power supplies use energy while standby, we are currently investigating if it is worthwhile to completely turn off these power supplies while in down time, but there are still some issues with the power supply controls.

Irradiation Experimental Area

The multi user facility used for most irradiation experiments has been upgraded after the move to the east side of the building [5]. The setup now consists of a modular design with standard elements positioned with 0.5 mm accuracy on breadboards, allowing quick changes to the setup between experiments. An automated modulator, degrader and dual collimator system allows quick changes to the beam. An automated xy-positioning system enables remote control of the device under test. Several other minor hardware changes and improved logistics have allowed us to considerable speed up experiments themselves as well as switching time between experiments. So, less energy use for the same service delivered to the users. Calibration procedures have also been standardized resulting in less loss of time

OPERATIONS

As indicated above, many minor changes to our operating procedures have contributed to energy efficiency. To promote a change in attitude a display showing current power consumption and the usage over the past week was installed in the cyclotron control room.

During the past years the scheduled available beam time has shifted from two continuous periods a year with a winter and summer break for maintenance, to a 3+3 block system. The current three week long downtime periods are long enough to enable us to turn off several major power consuming components and run the cryostat on cold gas. At the same time the available up-time is sufficient to cater to our users for irradiations and radio-biology as well as the occasional longer experiments. Most maintenance can be performed during the down-time periods, relieving the need for manpower during the summer vacation. At the same time the operator staff, who only have a half-time employment as operator and are part of the electrical engineering staff for the other 50%, have sufficient uninterrupted time to work on projects for other groups within the laboratory.

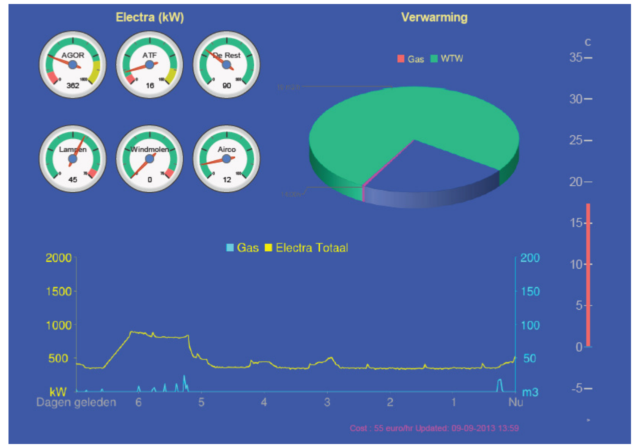

Figure 3: Control room display.

OUTLOOK

In order to make this process successful continued attention is necessary. Every new component that is added to the system should be reviewed on their power consumption and reliability as well as purchase cost. Changes in the system to improve flexibility and efficiency are still possible, though the rate of return is less than that of the measures already taken, but depending on the time of operation left for our cyclotron the investment can still be beneficial.

The simple addition of an energy monitor in the control room has had a positive psychological effect making people more energy conscious. Continued involvement of the technical staff encourages a more widespread change in behaviour and provides new suggestions for improvements.

ACKNOWLEDGMENT

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