AUSTRON, A CENTRAL EUROPEAN PULSED SPALLATION NEUTRON SOURCE

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Abstract

After the disintegration of the Iron Curtain, Austria declared its intention to build a centre of excellence for scientific research in the central European region. The choice of a spallation source became clear in 1991-92 and the addition of a medical facility, now known as the Med-AUSTRON, quickly followed. A major design report appeared at the end of 1994. AUSTRON, at that time, was planned in stages that would culminate in two target stations, a muon physics facilty, a test beam for detectors, a medical facility and a maximum average power of 410 kW at 50 Hz. In the years that followed, the design was reviewed. Dual frequency schemes for both the radio-frequency and the main resonant power converter have been studied to reduce the particle losses while increasing the average power to 500 kW. More recently, a second ring has been proposed as a bunch accumulator that will operate at 10 Hz, with five times the particle intensity per pulse of the standard 50 Hz operation. The original premise that reliable and known technology would be used, but in a custom-built and innovative way, has been respected throughout the development.

1 MISSION AND STATUS

The fall of the Berlin Wall in November 1989 and the subsequent disintegration of the Iron Curtain ended half a century of division for central Europe. Austria changed from being on the edge of two large political and economic regions to being at the centre of the reviving central European region. Anticipating the needs of this new situation, Professor M. Regler started campaigning for a centre of excellence for scientific research with an international and multidisciplinary character that would stimulate the latent synergy that had hitherto been stifled. In the first instance, the exact definition of the centre was left open. Among the possibilities were a synchrotron radiation facility, a centre for microelectronics and a computer centre, but whatever the final choice, the centre was seen as a way to:

- develop the new geopolitical status of the region,
- prevent the ‘brain drain’ of young scientists,
- improve the balance of scientific exchanges with other regions
- encourage technology transfer and spin-off,
- create a post graduate centre,
- equip the region with a tool for world class research.

A commission was set up under the patronage of the Austrian Academy of Sciences (Chairman Professor P. Skalicky, Technical University of Vienna; Secretary General Professor M. Regler, Institute of High Energy Physics of the Austrian Academy of Sciences) to study a project, provisionally called AUSTRON, that would fulfil this role. At a meeting of the “Pentagonale” in Spring 1991 in Bratislava, the decision was taken to declare the AUSTRON as a neutron spallation source. In October of that year in CERN, the idea was further developed and endorsed by a panel of experts representing more than 50 research institutions during a working week of the “Hexagonale” (later to become the Central European Initiative). The AUSTRON was seen as being of the correct size for the region. It would attract a multidisciplinary user community that included industry. The activities of such a centre were seen to be a valuable catalyst for technology transfer and spin-off. This decision should also be seen in the context of the world demand for neutrons. This was, and still is, expected to be strong in view of the pending closure of many nuclear reactors that are presently the main source of neutrons for science. With widespread public reluctance to authorise new reactors and the increasing severity of safety regulations, the world’s scientific community has recognised for some time the inevitability of a ‘neutron drought’ in the early decades of the 21st century [1]. The supporters of AUSTRON also realised that synchrotron-based neutron sources can be easily combined with muon and neutrino facilities, which adds a strong element of basic physics research. The addition of a medical facility that could share the linac for the acceleration of carbon ions for cancer therapy completed the original vision of AUSTRON. By the end of December 1992, Dr E. Busek, then Minister for Science and Research, had officially declared the support of the Austrian Government for the AUSTRON.

An International Scientific Advisory Board was founded in 1993 under the chairmanship of Professor A. Furrer, Paul Scherrer Institute, and a detailed study of the AUSTRON centre was published in November 1994 [2] with the help of CERN, the research centre Siebersdorf, the Technical University of Graz and several international experts and industrial firms. In Spring 1996, the Austrian Government invited the European Science Foundation to make an independent assessment of the competing Austrian projects AUSTRON and EURO-CRYST. Their report [3] was published in October 1997. The assessment panel endorsed the concept of AUSTRON as “a high-performance research facility of medium to large scale" that would "serve excellent 'small' science". The panel recorded its concern for the establishment of funding "before new initiatives elsewhere will make the AUSTRON scientifically less attractive". The panel felt that EURO-CRYST could "as a 'distributed laboratory' (and with the reduced size of that) make excellent sense in a national context". As a consequence, the Austrian Government requested the preparation of an AUSTRON project proposal [4] for international presentation. In May 1998, at a meeting chaired by Professor H. Rauch, the proposal was made and accepted to add a second ring as a bunch accumulator for a 10 Hz target. This significant addition to the base design multiplies the neutron flux by five, which greatly increases the acceptance of the project by the user community and brings it into direct comparison with the proposed European Spallation Source [5] and the approved Spallation Neutron Source [6] in the U.S.A. In August 1998, Austria pledged one third of the total cost of the AUSTRON and invited international partners to participate in the construction. More recently, this pledge has even been increased.

2 AUSTRON BASE DESIGN

The AUSTRON study [2], divided the construction of the centre into a number of stages and options. Figure 1 shows the complete accelerator complex and Table 1 summarises the parameters of the final stage that will be referred to hereafter as the *base design* with all options included.

Table 1: Performance of the AUSTRON base design.

H minus / proton operation	
Injection to RFQ [keV]	70
Injection to DTL [keV]	750
Injection to RCS [MeV]	130
Energy on target [GeV]	1.6
No. of particles delivered per cycle	3.2×10^{13}
Repetition rate [Hz]	50
No. of targets	2
Average beam power [kW]	410
Light-ion operation	
No. of C^{4+} or O^{6+} ions per second	2×10^{9}
Energy of partially stripped ions from DTL [MeV/u]	28
Options	
(1) Medical synchrotron delivering ≤ 425 MeV/u of fully stripped C^{6+} or O^{8+} ions for penetrations ≤ 30 cm and ≤ 24 cm respectively.	
(2) Transmission muon target intercepting ≤ 5% of the beam to target no. 1 (assuming both targets receive 25 Hz).	
(3) Low-intensity beam line for ≤ 10^{12} particle/pulse for detector R&D. The beam would be uniformly spread over 10 m^2.	

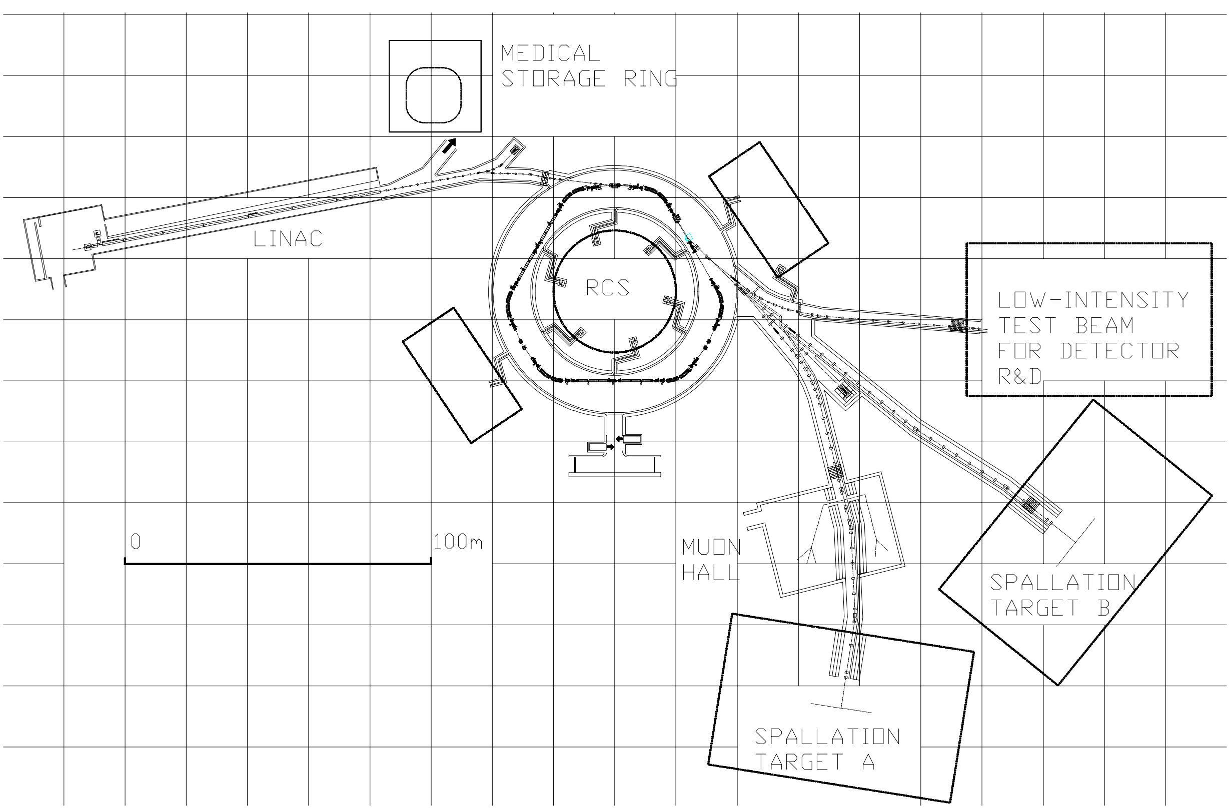


Figure 1: Layout of the AUSTRON accelerator complex in the base design

2.1 Injection chain

The acceleration of different particle species in the same linac has been demonstrated at CERN, but the AUSTRON was somewhat unique in having this feature designed into the linac from the beginning. However, in the most recent studies, the medical facility has been given its own dedicated injection chain [7]. Figure 2 shows the original layout.

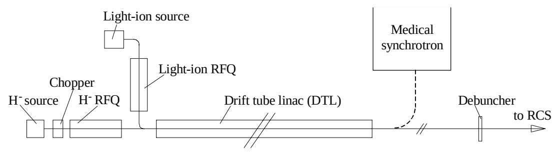


Figure 2: Schematic layout of the injection line

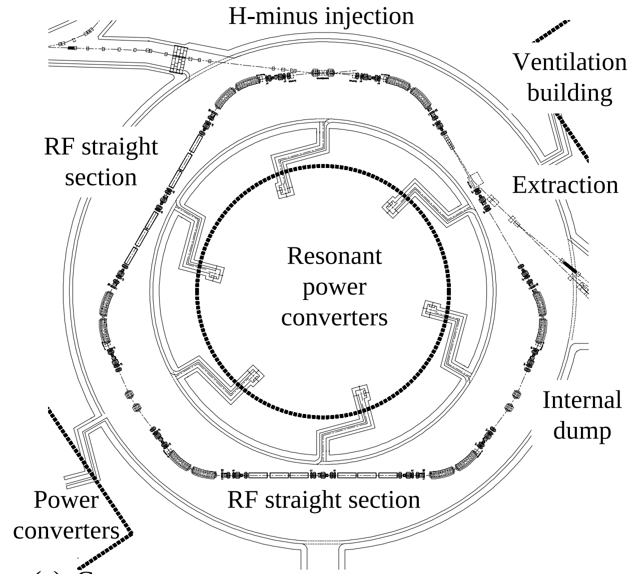
The H^- ion source needs to deliver a minimum pulse length of 93.5 μs at 50 Hz with an average current during the pulse of 104 mA. This is beyond currently available sources, but within reasonable expectations for future development. The chopper was included to reduce losses at injection, but was not used in the basic design. The debunching cavity is essential to combat the space-charge and to reduce the injected momentum spread. The beam is collimated along the linac to remove betatron and momentum tails (~0.8 kW absorbed power).

2.2 Injection into the rapid cycling synchrotron

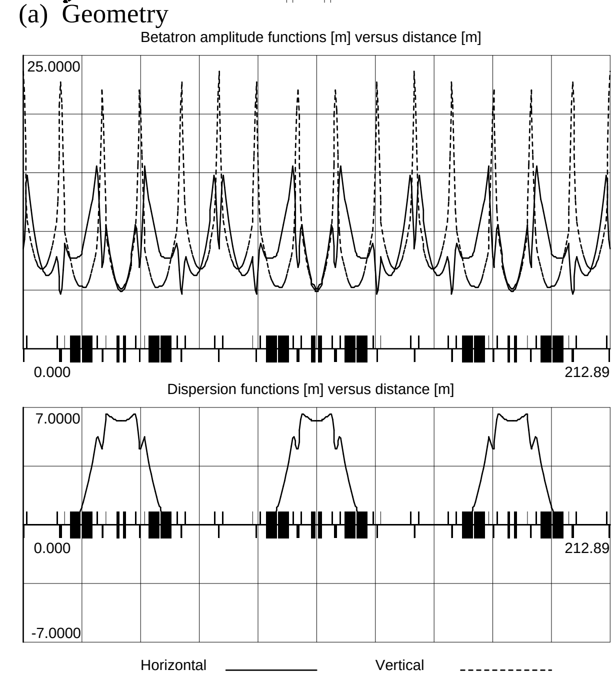
The injection into the rapid cycling synchrotron (RCS) is a classic H^- scheme. A full-height stripping foil is placed on the inner (low momentum) side of the aperture. The main field varies sinusoidally about a dc offset such that it does not change sign. Injection takes place on the downward slope just before the minimum of the cycle. The closed orbit in the ring for the injection momentum is drifting outwards at this time. Fast bumper magnets in the ring modify this horizontal drift and a vertical bumper in the injection line provides a co-ordinated sweep in the vertical plane. The combined effect is to 'paint' the ring aperture over 63 turns with a correlation between the horizontal and vertical motions that combines large horizontal betatron motions with small vertical motions and vice versa. This paints a quasi-uniform beam in the two phase spaces. Owing to losses along the injection chain only 55 mA of the 104 mA from the source are stored in the machine.

2.3 RCS, aperture and collimation

The RCS lattice is based on a triplet structure. The geometry and the non-space-charge lattice functions are shown in Figure 3. The dipoles and main quadrupoles are powered individually by three resonant converters. There are four tuning quadrupole circuits that can be used to manipulate the working line in the tune diagram.



(a) Geometry



(b) Lattice functions

Figure 3: Geometry and lattice functions of the RCS

The machine aperture is based on the total geometrical beam emittances after 'painting'. In the vertical plane, the emittance is taken at injection ($E_z = 476\ \pi$ mm mrad), but in the horizontal plane, the value at approximately 1 ms into the rf programme is taken when the beam momentum spread reaches its peak ($E_x = 441\ \pi$ mm mrad and $\Delta p/p = \pm 0.0044$). To these beam sizes are added closed-orbit margins of ±3 mm and collimation margins of ±17 mm in each plane. These margins are maximum values that are scaled by $\sqrt{(\beta/\beta_{max})}$ around the ring. The beam sizes plus the closed-orbit margins define the 'good-field' region required from the magnets and the collimation margins occupy the 'poor-field' region. The collimation margin is an extremely important part of the loss management. Nominally, ±5 mm is reserved for the stepback of the secondary collimators from the primary collimators that define the beam edge and the remaining ±12 mm is for the multi-turn capture of particles that escape or are scattered out of the secondary collimators. Apart from the collimators themselves no equipment is allowed within this space. The collimation system was expected to absorb ~9.3 kW. Additional absorbers are included to intercept the unstripped H^0 beam (~0 kW), the electrons coming from the stripping foil (~0.02 kW), the protons that escape the rf trapping and spiral inwards (~4.3 kW) and the full beam for emergency internal dumping (intermittent at 8.2 kJ/pulse).

The outer limit of the collimation region is defined by the rf cage that follows (approximately) the form of the beam envelope. A minimum of 5 mm has been allowed for the rf cage. When aligned with the magnetic field, the cage can be formed from stainless steel sheets, but in general it is an array of closely-spaced wires. Inside the magnets, the vacuum chambers are ceramic with an internal high-resistance coating to bleed away static charges.

The beam remains in the RCS for a relatively short time (~10 ms), but the peak current at top energy is over 75 A, which makes collective effects a serious concern. Low order longitudinal instabilities are relatively benign with low growth rates. Transverse instabilities are about an order of magnitude faster. However, the machine is expected to be stable, but this conclusion is subject to a detailed impedance inventory being made of the final design

2.4 RF trapping [8]

The RF system has 12 cavities (11 to cover operating requirements and 1 installed spare) of nominally 22.5 kV each. The units fill completely two 'sides' of the ring (see Fig. 3). It may be possible to shorten these cavities by using VITROVAC®[1] rather than ferrite [9]. At 50 Hz, with a harmonic number of 2, there is insufficient time for adiabatic trapping and the capture of the injected beam was optimised numerically using the code LONG1D [10]. Losses in trapping and early acceleration were 10% (without chopping), which is comparable to those at ISIS and considered as an upper limit. If chopping is used, the losses are reduced to 2%, but there will be an increased incoherent tune shift and loss on transverse non-linear resonances. This situation is reviewed in Section 3.1.

2.5 Extraction

The extraction is based on a full-aperture, ferrite kicker operating in the horizontal plane and deflecting the beam to the outside of the ring across a current-wall septum. Towards the end of acceleration, a slow bump will be applied bringing the beam to the edge of the aperture against the current-wall septum. The fast kicker comprises six modules (one installed spare) with a total length of 2.453 m, a rise time of ≤ 175 ns and a flat top variable up to 950 ns. The rise time was based on a more stringent requirement for the acceleration of medical light ions that has since been abandoned and the rise time could now be relaxed to ≤ 320 ns. The integrated field is 0.142 Tm, giving a kick of 0.018 rad at the top energy of 1.6 GeV. The current-wall septum is in the same straight section. It is 2 m long with a field of nearly 1 T giving a deflection of 0.250 rad. The septum is dc, mounted outside the vacuum and the chamber of the main ring is made magnetic at this point to provide shielding from the stray field.

2.6 Targets

The planned target design is a flat-block made of a tungsten rhenium alloy W5Re with edge cooling. This design has the advantage that the target coolant is not irradiated directly and corrosion is reduced. However, this design is close to a technological limit for cooling when operating at 0.5 MW.

2.7 Loss Management

Loss management is the key issue in pulsed spallation sources. The activation of the released air and water must be monitored and kept below limits agreed with licensing authorities. Ventilation systems need low replacement rates (< 2 per hour). High-loss areas can be 'sealed' and the air slowly leaked to lower loss areas that provide buffer storage before release. An under-pressure is needed to prevent out-leaks. All exhaust air must be filtered to remove ^{7}Be and other aerosols. Intermediate storage of waste water, shielding of ground water and secondary cooling circuits are all standard considerations. The degradation of materials such as coil insulation needs to be estimated and radiation-hard elements used in critical places. Remote handling will be needed for the stripping foil and targets. Dust, especially from fractured stripping foils, must be trapped and exhaust air from roughing pumps must be filtered. The collimator and beam control systems must be highly efficient and machine operation must be interlocked to a beam loss measurement system.

In much of the machine the losses will be low in absolute terms, but then the issue is to keep them below ~1 W/m in order to allow 'hands-on' maintenance. Finally, in the medical area, absolute radiation levels are very low, but staff and members of the public will be spending long periods of time close to treatment rooms. Consequently, the residual radiation levels outside the shielding walls must be much lower than in the spallation part of the complex.

Shielding and other loss issues were based on the

[1] Vacuumschmelze Gmbh, PO Box 2253, D-6450 Hanau 1.

assumed (maximum) losses in Table 2.

Table 2: Assumed losses throughout the complex

	Energy [MeV]	Power [kW]
Continuous losses		
Chopper	0.07	0.007
RFQ	1	0.04
1st tank of DTL	10	0.3
Collimation in injection line	130	0.8
Unstripped beam collector	130	0.8
Untrapped beam	150	4.3
Collimation at start	150	0.9
Collimation at extraction	1600	9.3
Remaining loss points in RCS	1600	0.4
Muon target (5% at 25 Hz)	1600	10
Main target	1600	410
Semi-continuous losses		
External dump for linac	130	40
External dump for RCS	1600	20*
Intermittent losses		
Internal RCS dump	1600	10 kJ

* External dump is rated for only 2.5 s continuous operation or 2 pulses per cycle for machine development.

3 PROPOSED IMPROVEMENTS

3.1 Dual frequency magnet cycle

While there was a clear indication that the AUSTRON should be upgraded to 0.5 MW, it was also clear that a 10% injected beam loss (Section 2.4) was becoming more unacceptable with time. Simulations showed that, at 0.5 MW for a 50% chopped beam, losses could be cut to 4.4% without momentum painting, but *the objective was to reduce losses below 1%, which was achieved by adding a dual frequency to the magnet cycle* [11, 12] that dilated the up-ramp and shortened the down-ramp.

3.3 Addition of an accumulator ring [13]

The addition of an accumulator ring to store 4 consecutive pulses that could be ejected with a fifth pulse from the RCS delivers a 10 Hz beam to the target with an intensity per pulse of 5 times the standard 50 Hz operation. Since accumulation is made at 1.6 GeV, the space-charge limitation is removed. This mode of operation, however, imposes the harmonic number of 1 on the main ring rf system and the implications of this change have yet to be studied. The second ring would be in the same hall as the main ring and stacked above it. However, it would be costly to raise the roof, so the rings are best placed in nearly the same plane with only a small offset to separate the vacuum systems and to avoid any space-charge lens effects on the low-energy beam in the main ring.. The second ring could look very different to the main ring with higher field dipoles, all metallic chambers and a smaller aperture, since it is dc.

4 CONCLUSIONS

The original AUSTRON study [2] provides a reference design. Later studies showed that, with a dual-frequency magnet cycle, the theoretical trapping and acceleration losses can be reduced, possibly below 1%, which will be a key factor in gaining approval for the project. More recently, the high desirability of having a second accumulator ring has been accepted. Feasibility studies of dual-frequency resonant power converters and the accumulator ring are now urgently needed and will have to be followed by a revision of the main ring design, before an execution design can be made.

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