INTERFACING THE SIN RING CYCLOTRON TO A RAPID CYCLING SYNCHROTRON WITH AN ACCELERATION AND STORAGE RING ASTOR.

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Summary

A rapid cycling synchrotron is the most economic solution to produce intense proton beams of the order of 20 GeV for research with antiprotons, kaons, neutrinos, hyperons and mesons. The ASTOR concept offers itself as an interface between the SIN 590 MeV ring cyclotron and such a synchrotron. The so called phase expansion effect is used to stack more than a hundred turns at the extraction radius of the isochronous acceleration and storage ring ASTOR. Extraction of this stack with a fast kicker produces an intense pulsed beam with a repetition rate of 3000 Hz. Parking the ASTOR pulses in a four level accumulator makes this beam suitable for further acceleration in a rapid cycling synchrotron. In order to minimize overall costs of ASTOR and the synchrotron a final energy of 1.3 GeV is chosen as a reference design of ASTOR. With a 50 Hz repetition rate for the synchrotron an average beam current of 80 µA can be expected.

Introduction

Cyclotrons can produce intense proton beams of the order of 100 kW with 100 % duty cycle, as the example of the meson factories at TRIUMF and SIN have shown. Unfortunately the cyclotron principle seems to have a practical limit of well below 20 GeV[1] due to problems with turn separation and vertical focusing at extraction. A rapid cycling synchrotron, on the other hand, is capable of accelerating intense beams to 20 GeV or more. However if we want to use the SIN cyclotron as an injector for such a synchrotron, it is necessary to use an acceleration and storage ring ASTOR as an interface (see figure 1). The ASTOR concept[2] was originally conceived for a 2 GeV accelerator offering alternative modes producing either a continuos or pulsed beam. When used as an interface, only the pulsed mode of ASTOR is needed, which allows some saving in the RF system.

The ASTOR interface

The energy of ASTOR is chosen as 1.3 GeV on the basis of overall cost optimisation. A lower energy would make ASTOR cheaper, but at the cost of reduced intensity and increased ferrite tuning in the synchrotron, (see fig.2). A layout of ASTOR is shown in fig.3. The sector magnets weigh about 150 t each and have hill fields increasing from 14 kG at injection to 19 kG at extraction. The harmonic number is 12, compared with 6 in the existing ring cyclotron. This preserves the flexibility to use reductions of 1:2, 1:3 or 1:6 in the micropulse structure for improved timing experiments.

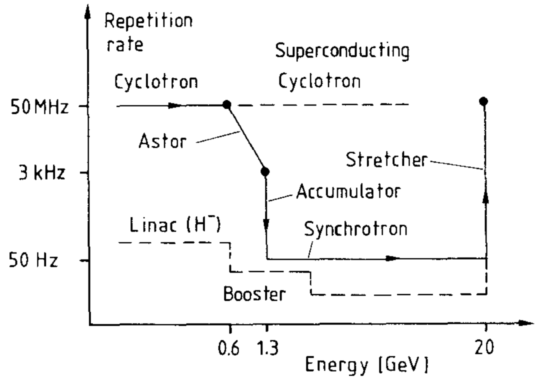

Figure 1: Repetition rate versus energy for proposed SIN accelerator complex. The continuos beam with a 50 MHz micro structure from the existing ring cyclotron is ideal for counter experiments with time of flight techniques, but is difficult to accelerate to 20 GeV with a cyclotron, even if it is made with superconducting magnets. It is thus necessary to convert the cyclotron beam into a pulsed one with an intermediate acceleration and storage ring ASTOR and then accelerate it further in a rapid cycling synchrotron of 50 Hz. A stretcher ring with slow extraction gives finally back a continuos 50 MHz beam structure. An alternative approach, as indicated in the figure, is to inject an H^- beam from a Linac into a booster synchrotron before transfering it to the final synchrotron.

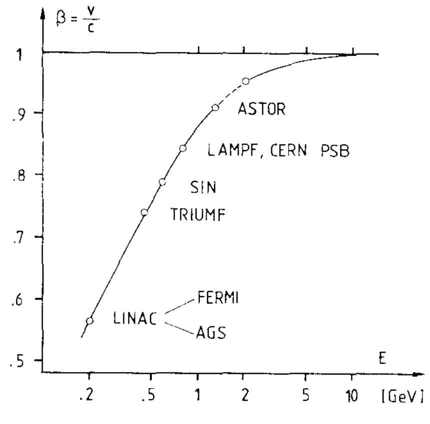

Figure 2: Relative particle velocity versus energy for different accelerators. Since the RF frequency of a synchrotron is proportional to velocity, one likes to be as close as possible to the velocity of light already at injection in order to minimize the amount of ferrite tuning. The two points for ASTOR correspond to the chosen energy of 1.3 GeV and to the original, but more expensive, 2 GeV version.

Fig.4 shows how the so called phase expansion effect[3] is used to stack about 120 turns in a 10 mm interval at the top energy. Fast extraction of this stack is made easier in the vertical direction (see fig.5), by keeping the vertical focusing relatively weak (Qy=0.6). The requirements for the fast kicker are similar to those for the 720 Hz kicker presently under test for the LAMPF storage ring[4].

Reference Design for a 20 GeV Synchrotron.

In an isochronous cyclotron the magnetic field is static and the RF frequency stays constant. The repetition rate of ASTOR is thus only dictated by the kicker, and is chosen as 3000 Hz for our scheme. Synchrotrons on the other hand are limited in the cycle rate to about 50 Hz. Transfering the beam from ASTOR to such a rapid cycling synchrotron requires thus an accumulator ring, which parks the ASTOR pulses at the fixed energy of 1.3 GeV. This accumulator is designed to have 4 levels like the CERN booster, because multiturn injection into one level is handicapped by the loss of coherence between successive pulses, due to the long time interval involved. Recombination of the four different levels into a single beam for injection into the synchrotron is foreseen to follow similar lines as the successive scheme of the CERN booster[5]. The two upper levels and the two lower levels are first merged to-

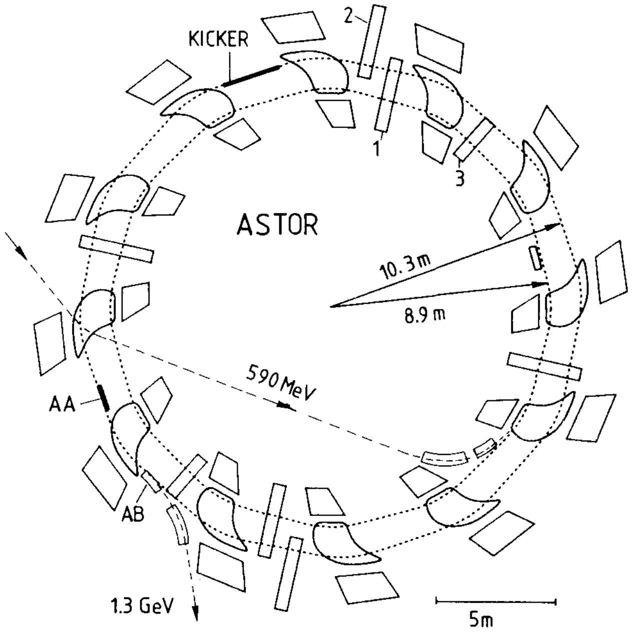

Figure 3: Layout of 1.3 GeV ASTOR. This isochronous cyclotron consists of 12 sector magnets and 8 RF cavities of 3 different types. Cavities of type 1 and 2 operate at 50 MHz and are responsible for the stacking process at extraction. Cavities of type 3 resonate at 100 MHz and give a voltage distribution with a flat top. They are also used to compensate the linear part of the longitudinal space charge forces. A fast kicker deflects the stacked beam vertically into the extraction magnet AA.

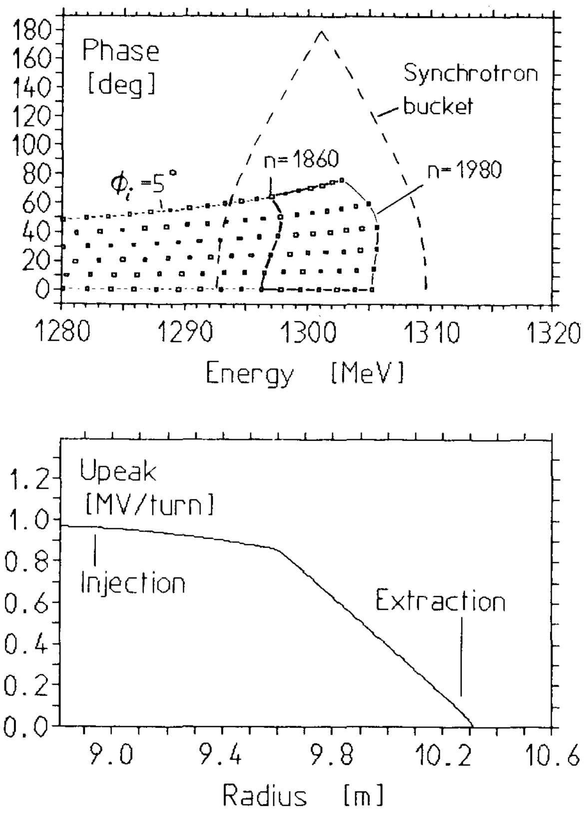

Figure 4: Phase expansion and stacking process in ASTOR. The decrease in peak energy gain per turn as a function of radius (bottom part) leads to a phase dependent magnetic field. This field debunches an initially narrow phase width beam of 2Φ_i =10° adiabatically to about 150° (top part). Turns n=1860 to 1980 are contained in a 10 mm interval with 10 MeV energy spread and can be extracted in one revolution with a fast kicker. This beam fits well into the synchrotron bucket as shown. Calculations were performed however without taking space charge forces into account.

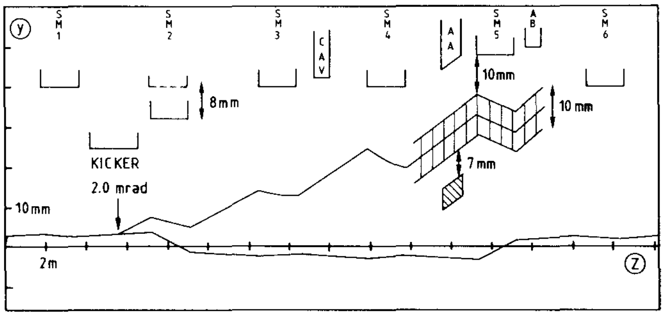

Figure 5: Vertical extraction from ASTOR. Shown is the vertical beam position y as a function of the orbit length z for half a revolution or 6 sector magnets.The stacked beam is deflected vertically 2 mrad by a fast kicker and extracted radially by the magnets AA and AB. In order to enhance the vertical clearance between the extracted beam and the magnet poles, which have a gap of 80 mm, the sector magnets SM2 and SM5 are displaced vertically by -8 and +8 mm respectively. This shifts the equilibrium orbit of the stacked beam by about 4 mm as seen in the undeflected beam.

gether vertically. The resulting two beams are then combined horizontally into a single beam. The increased emittance of the combined beam is still acceptable for the synchrotron and gives a space charge tune shift of only 0.06 for 10**13 particles per pulse.

The synchrotron needs a peak voltage gain of 9 MV/turn, due to the high repetition rate of 50 Hz. The anticipated high beam power, on the other hand, requires anyhow a powerful RF system, in order to keep the beam loading within controllable limits.
The full accelerator complex is illustrated and explained in the figures 6 to 10.

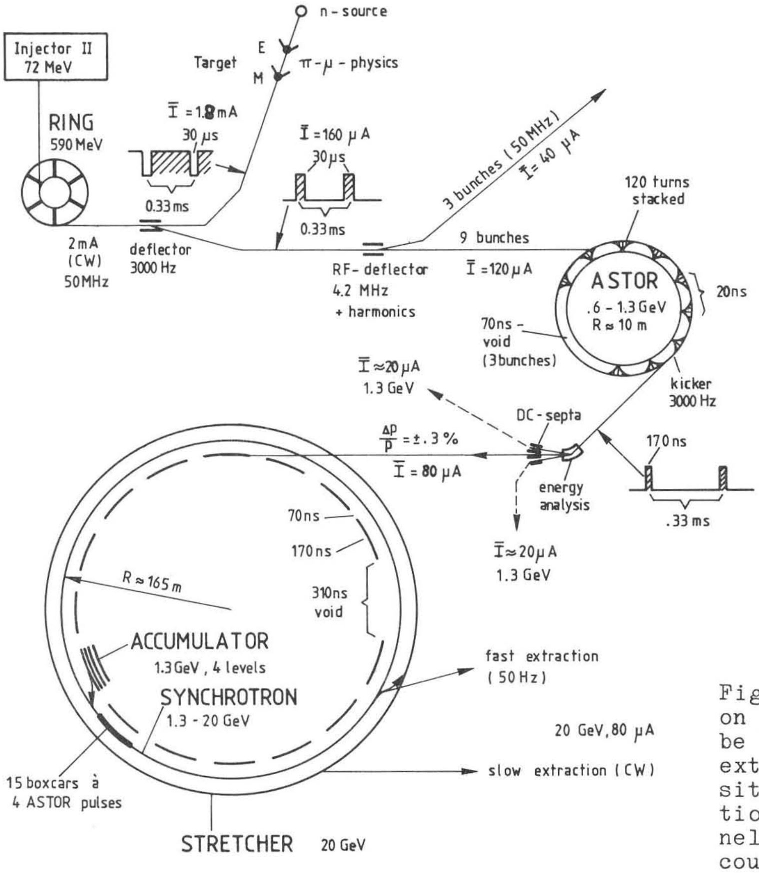

Figure 6: Scheme for a rapid cycling synchrotron complex at SIN. The future 2 mA beam from the 600 MeV ring cyclotron will go mainly to the present meson targets M and E and to the planned spallation neutron source. The beam will be deflected for 30 µs (or 9 % of the time), with a repetition rate of 3000 Hz, towards ASTOR, which accelerates the protons to 1.3 GeV. The 30 us long pulse gives 120 ASTOR turns, which are stacked at the final energy and extracted in one revolution. In order to reduce extraction losses a void of 70 ns is created by deflecting 3 out of 12 50 MHz bunches before injection into ASTOR. Nonlinear longitudinal space charge forces in ASTOR will produce energy tails, which have to be eliminated through an energy analysis. The 170 ns long ASTOR pulses are first parked in an accumulator ring of 165 m radius containing four levels. We are thus able to park 60 (=4*15) ASTOR pulses, which are then transferred into 15 boxcars of the 50 Hz synchrotron. After acceleration to 20 GeV the beam will be "fast" extracted for use by an external target or the stretcher ring. The beam would then be "slow" extracted from the stretcher during the 20 ms interval between pulses. The anticipated average beam intensity is in the order of 80 µA.

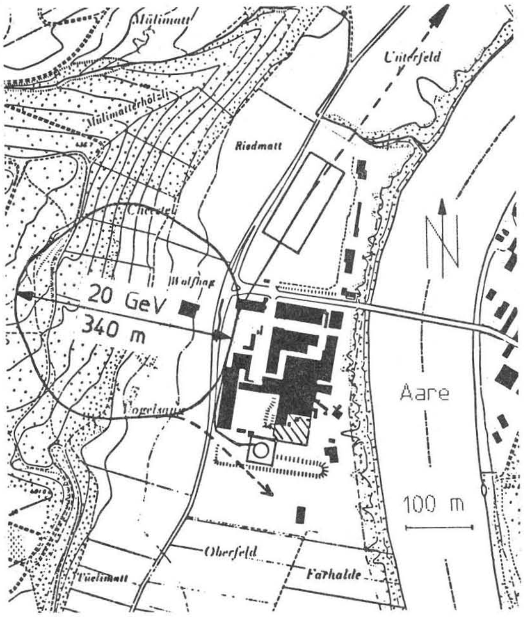

Figure 7: Possible layout of a 20 GeV tunnel on the SIN site. The pentagon shaped ring would be buried inside the mountain, while the slow extracted beam is used in an experimental hall situated to the north of the present installations. A several hundred meter long muon channel is also indicated. A fast extracted beam could be utilized in the southern part of the site for experiments with neutrinos and antiprotons.

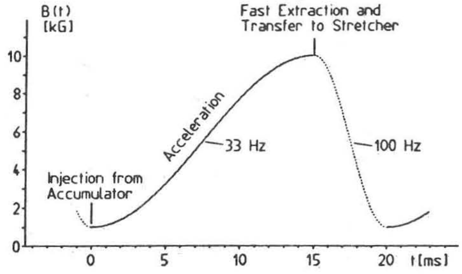

Figure 8: Magnetic field as a function of time in the synchrotron. To reduce the voltage requirement for acceleration with a 50 Hz repetition rate the use of dual frequency resonant circuits[6] is foreseen. During acceleration each magnet circuit, consisting of 4 magnets, one choke and a capacitor bank, resonates at 33 Hz. After extraction an additional capacitor bank is switched on in parallel in order to raise the resonance frequency to 100 Hz during the recovery process. Injection and extraction occur in one single turn at the field extrema of 1 kG and 10 kG respectively.

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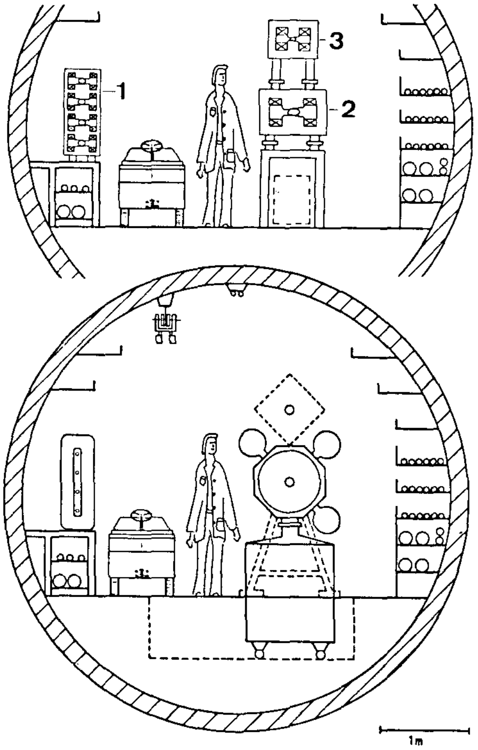

Figure 9: Possible layout of the tunnel housing the accumulator, synchrotron and stretcher ring. The upper picture shows a cut through an arc section with the combined function bending magnets. The four level accumulator ring (1) operates at the fixed energy of 1.3 GeV and parks the beam pulses from ASTOR, before combining them into one single beam for injection into the synchrotron (2). The rapid cycling synchrotron accelerates the beam up to 20 GeV and then transfers it to a stretcher ring (3) or directly to the experimental facilities. The lower picture shows a straight section containing RF equipment. Of the synchrotron we see a cavity with three ferrite tuners, of the accumulator a 50 MHz buncher cavity and of the stretcher a quadrupole. The diameter of the tunnel is assumed to be 4.8 m.

Acknowledgments

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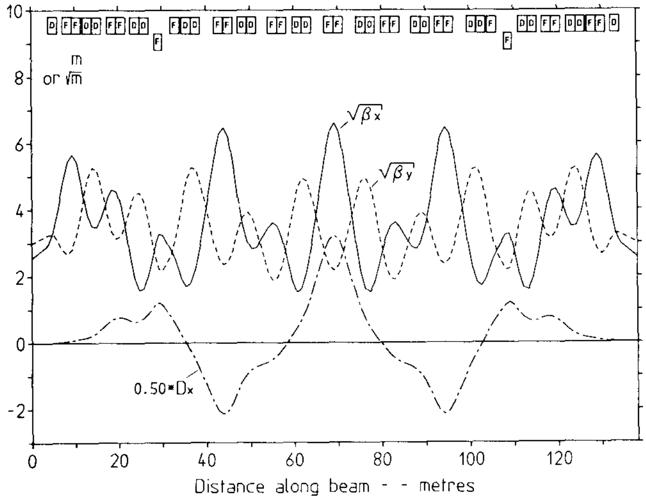

Figure 10: Horizontal and vertical beam envelopes and dispersion Dx in the synchrotron. Shown is a possible layout of an arc section in the pentagon lattice, consisting of 42 combined function magnets and 2 quadrupoles. Unequal drift spaces between the magnets and the 2 quadrupoles force the transition energy to 26 GeV, well above the maximum energy of the synchrotron, and provide the dispersion matching to the dispersionless straight sections containing RF equipment, injection and extraction elements.

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