MODES OF OPERATION FOR THE COOLER RING COSY

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Summary

An electron cooling synchrotron (COSY) is under study at the KFA Jülich. This synchrotron can operate as storage ring using internal targets as well as delivering external beams. The K-value 540 of the ring has been chosen to match the high resolution spectrometer BIG KARL which will be the first important instrument at the ring. Injection into COSY will be done with the existing JULIC cyclotron via stripping respectively stacking injection or with the SNQ-LINAC of the proposed neutron spallation source.

Introduction

A storage ring with an electron cooling section and using internal targets looks like a very promising way for opening new fields in medium energy nuclear physics and has stimulated various activities for the realisation of such devices[1,2,3]. Therefore, a group consisting of KFA scientists and members of the surrounding universities has been formed to study the potentialities of such a new device to be built at the KFA Jülich. An important element in those considerations is the perspective of having a side-beam from the proposed high intensity Spallation Neutron Source-Linac (SNQ-Linac)[4]. As the design of this accelerator is aimed to satisfy primarily the needs of the solid state physicists for a high intensity pulsed neutron source, the quality of the parasitic raw beam didn't seem very appealing in view of high precision nuclear experiments.

The advent of beam-cooling technology[5,6] led to the idea of the Cooler-Synchrotron COSY, which not only could convert the parasitic SNQ-Linac beam into a higher quality beam but also could accept the variety of particle beams presently produced with the Julich-Isochronous Cyclotron (JULIC) and accelerate them into a new energy region while at the same time raising the beam quality substantially. At a workshop[7] on electron cooling held in Bad Honnef 1982 principal ideas in that direction were discussed and led to a report[8] which laid down the considerations for a cooler concept.

Ring Design

The ring consists of six unit cells with the structure ODOFODO and is outlined in figure 1. The ring is extended on two sides. One side has two telescopes of 10 m length giving room for the electron cooling device. Opposite are two telescopes of the same length but with a different quadrupole configuration. Around the middle point of this section the scattering chamber is located that belongs to the high resolution, large mass-energy product spectrometer BIG KARL that is in operation since 1979[9]. For performing recoil coincidence experiments a smaller spectrometer has been added to the design. A variable dispersion at this target point is provided to allow matching to the adjustable dispersion of BIG KARL.

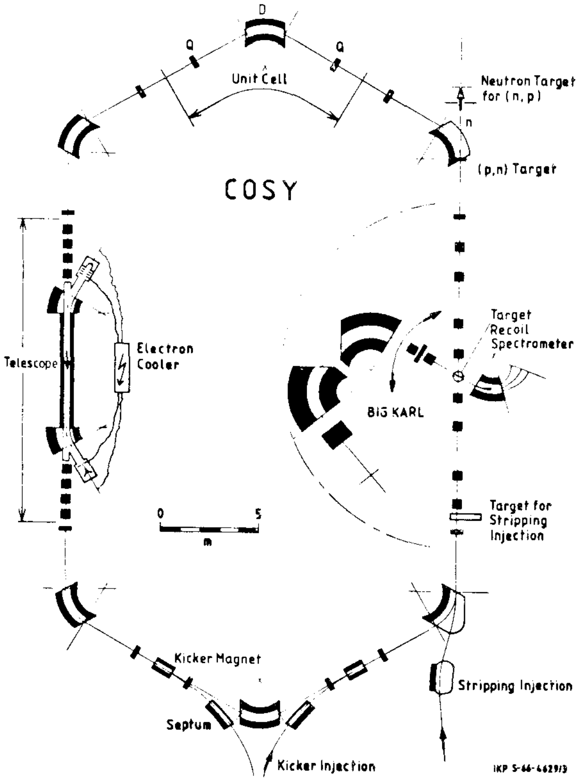

Figure 1: Schematic layout of the preliminary COSY-Ring.

Figure 2 shows the β-function and the dispersion of a unit cell of the ring for a specific setting. In figure 3 the dispersion is shown along the circumference of the ring. The target point is at s = 0. The magnification of the corresponding target telescopes is variable between 0.3 and 3.5. Accordingly the dispersion is adjustable from 1 to 10 m to satisfy the matching condition for the magnetic spectrometer.

The working diagram of the ring is depicted in figure 4. Not all resonances for Q_x and Q_z are shown. The curve represents the working point as a function of the dispersion. Two fixed points for D = 9.1 m and D = 2.1 m are marked.

The preliminary data of the ring are put together in table I. The large acceptance of the ring is chosen to obtain a high stacking factor for cyclotron injection and the accumulation of exotic beams. The circumference shown in the table is not finally set. At the moment we are favoring a value of approximately 116 m

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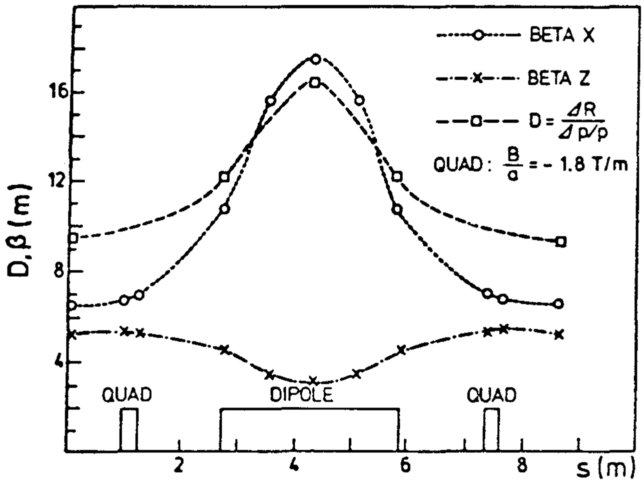

Figure 2: Betafunction and dispersion shown for one unit cell.

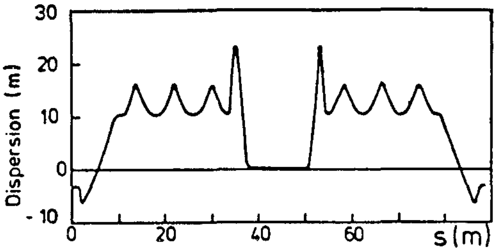

Figure 3: Dispersion shown along the ring circumference. The target is located at s = 0.

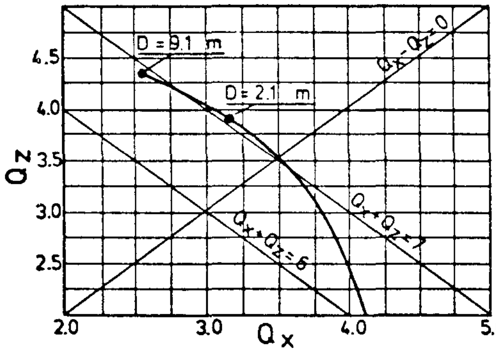

Figure 4: Working diagram of the ring. The dots mark the setting for a dispersion of 9.1 m respectively 2.1 m.

which is equivalent to 12 times the cyclotron circumference. This ratio gives higher flexibility for the different RF-modes in the ring.

Additional target stations are possible between the unit cells, but at the present stage of the project not laid out in detail. The RF structures which will be located at positions with a low dispersion allow manipulation of the beam in time structure and energy. The dipole magnets, which at the moment are designed for a bending power of about 500 MeV protons, will probably be changed to have the potential of bending protons above 1 GeV in a future upgrading, which many physicists feel to be an important domain.

6 unit cells of the structure O D O F O D O			
Two telestcopes of 10 m length with magnification +1			cooling section
Two telestcopes of 10 m length with magnification +1			target section
Circumference:			88.75 m
Dipolefield for 500 MeV protons ($p = 1.09 \frac{GeV}{c}$):			12.1 kG
Free length for cooling section:			9.8 m
Free length for BIG KARL:			2.25 m
Acceptance uncooled:		$\epsilon_x = 110\ \pi$ mm mrad	$\epsilon_y = 110\ \pi$ mm mrad
cooled:			$\epsilon_x = 0.15\ \pi$ mm mrad
Dispersion at target:			variable: 2 - 20 cm/%
The following values correspond to the dispersion D = 11 cm/%			
β-function	β_{target}:		$\beta_x = 6.6$ m $\beta_y = 5.2$ m
Maxima:	$\beta_{horizotal}$:		$\beta_x = 18.7$ m
	$\beta_{vertical}$:		$\beta_y = 5.2$ m
Q-values	$Q_{horizontal}$:		3.16
	$Q_{vertical}$:		3.95

Table 1: Properties of the preliminary COSY-Ring.

Injection Modes

A favorable situation exists for the COSY-Ring as there will be two injector machines: the old cyclotron and the proposed SNQ-Linac for high energy injection. The produced H^- beam would allow to fill the ring up to the space charge limit with stripping injection, while the normal high intensity proton beam could be injected via kicking injection. Only a small fraction of the SNQ-beam is needed to fill the ring completely. The time structure of the linac produces a batch of particles of 250 μs length with a repetition rate of 100 Hz. Each of those batches has $5 \cdot 10^4$ bunches with a spacing of 5 ns imposed by the 200 MHz accelerating RF of the linac. At the maximum proton current of the linac (5 mA) each of those bunches contains $6 \cdot 10^9$ particles. Thus few bunches will be sufficient to fill the ring to the expected space charge limit of 10^{11} protons.

In case of the cyclotron two injection methods are considered. The stripping injection for particle beams that have still electrons attached like H_2^+ or $^4He^+$. This injection mode will make it easy to obtain a good filling efficiency up to 10^5 turns, but would put limits in case of $^4He^+$ on the injection energy which then would have to be compensated through acceleration in the ring. The alternate filling mode is kicking injection which would make use of the full energy range of the cyclotron, but because of Liouville's theorem the number of particles injected into the ring is restrained to what is achievable by transverse and longitudinal stacking. The time structure of the cyclotron beam is a pulse with a width of ca. 3 ns having a spacing of 50 to 30 ns. This corresponds to energies of 22.5 to 45 MeV/n. Heavier ions up to Ne that will be feasible through the ISIS-ECR ion-source could be injected into the ring, too. In this case, because of the large charge exchange cross section the requirements imposed on the ring will be more severe in terms of the vacuum. For the same reason it seems that kicking injection is the preferable method.

Operational Modes

Depending on the requirements of the experiment different ways of operation have to be chosen. The desired projectiles, the energy, and the momentum resolution will set the bounds for what is attainable in performance.

In the recirculating mode the energy of the injected beam stays unchanged and only a small RF-voltage would be used to compensate the energy loss caused by the internal target. In this case the simple operation of the ring and the possibility of using standard target

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techniques is appealing, but both at the expense of a limited choice in energy and a somewhat restricted energy resolution. The main advantage of this mode, however, is the high gain in luminosity compared to a single pass experiment.

For this simple recirculating mode the SNQ-Linac is a very superior injector due to the possibility of producing side batches of beam with a lower intensity but free selectable energy that ranges from 100 MeV to 1100 MeV for the final stage of the SNQ project. This would remove much of the energy limitation that exists with the cyclotron as injector in this mode and give this storage ring a distinct advantage compared to the projects in Uppsala and Indiana which need the acceleration in the ring to get above 200 MeV protons.

Large energy changes in the ring are possible by using COSY as a synchrotron, which is of interest when the cyclotron is used as injector. The steps would be first to fill the ring, then accelerate to the requested energy, and then run the measurement as before. This gain in energy flexibility has to be payed for with a lower overall luminosity held against the direct recirculating mode.

Phase Space Cooling

Of special importance are the modes where the phase space is reduced through a cooling process. Electron cooling is certainly favorable for high circulating currents ($10^7 - 10^9$ particles) with good emittance. The steps would be filling, cooling, and measurement with a significant longer use of the beam, as heating effects of the target are compensated through the electron cooling process. As this is a slow process targets on the average have to be extremly thin ($<0.1\ \mu g/cm^2$). Nevertheless, the obtainable luminosities are quite high ($\sim 10^{32}\ cm^{-2}s^{-1}$) due to the high circulating current. In addition the spatial definition is extremly good because of the small cooled emittance of εx, εy $\sim 0.1\ \pi$ mm mrad. However, the important new feature is the narrow energy spread which ranges from 10^{-3} to 10^{-5} $\Delta p/p$ depending on the filling factor of the ring. This allows e.g. to study new fields in threshold physics by slowly varying the energy. This change can easily be accomplished by changing the voltage of the electron gun or in a faster way through betatron acceleration. Larger changes of energy could be performed with RF-structures which would allow to cover the full energy range of the ring. The present technology (Fermilab e^- gun)[10] of electron guns would allow efficient electron cooling up to 200 MeV protons. For energies beyond this point one would after filling cool the beam and then raise the energy to the desired value compromising the high quality of the cooled beam.

Stochastic cooling which has a disadvantage in case of high beam intensities in the ring and is limited in the achievable momentum resolution can be of interest as a complementary process in the case of exotic beams like tritium. These particles could be produced in a nuclear reaction with a deuteron beam via $^7Li(d,t)^6Li$. As the tritons would have to be collected in a large phase space to give enough yield, the stochastic cooling is preferable and could be followed by electron cooling to reach the highest beam quality and remove target heating. As the present stochastic cooling technology is still in progress, substantial improvements can be expected in the future and may make it attractive in regimes where it now looks inferior.

Extraction of the beam will also be provided for experiments where low beam intensities are useful. A slow extraction mode[11] could spill out the beam after it has been prepared in the ring for the experiment. The extracted beam intensities would be in the nano-Amp region.

Experiment Stations

For high resolution particle spectroscopy the magnetic spectrometer BIG KARL is the main device on the ring. It would allow to produce high resolution spectra of protons up to 500 MeV. With the present spectrometer an angular range of 10° to 170° would be accessible by using clockwise and counter clockwise circulation of the beam. Scattering angles smaller than 10° are possible by the use of a septum magnet. The reduction in solid angle which is necessary for such a concept represents only a modest disadvantage for the forward directions.

In case of the recirculating mode standard target techniques could be used. The internal targets get very difficult in case of high resolution cooled beams, where an average thickness of a few hundred nanograms has to be achieved. One way is to use a thin fiber target of the nucleus under investigation, but this restricts the choice within the periodic table. An alternative are gas jet or cluster jet targets which are of course a technological challenge in the vicinity of the ultra high vacuum of the ring. A special operation of the ring which is named bypass mode looks like a possibility of using standard targets even with cooled beams. The idea is to circulate the beam not intersecting the target and only every hundredth or thousandth turn would be deflected and pass through the target by using a kicker system, thus giving the beam enough time to cool down again. But further study is needed to evaluate the practical implementation.

The use of polarized atomic beam targets which does not look exciting in single pass experiments is attractive in view of the high circulating polarized beam currents in cooled storage rings. The free choice of manipulating target and projectile spin is very appealing for experiments which try to look for the spin-spin interaction. A separate scattering chamber located between the unit cells could be dedicated for these kind of experiments.

Conclusion

At the present stage of the COSY project many details of the ring and its components are not finally settled. Adjustments will be made according to the progress in the calculation of the ring lattice and to accommodate changes in the demands of the various experiments. The present design holds the potential for novel experiments in the field of high precision nuclear physics. The possibility to make efficient use of the side-beam of the proposed SNQ-Linac, besides using the cyclotron beams, would make it a powerful addition to the Jülich cyclotron facility.

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References

1 The IUCF COOLER-TRIPLER. Proposal for an advanced light-ion physics facility, IUCF (1980), Indiana
2 Workshop on the Physics Program at CELSIUS, Nov. 1983, Uppsala
3 Workshop on "Electron Cooling and Beam Circulation" Jan. 1984, RCNP, Osaka
4 ICANS 7 Meeting "Zusammenstellung der KFA SNW Vortragsunterlagen" SNQ/CY25 10-83, to be publ. in IEEE
5 G. Budker and A. Skrinsky, Sov. Phys. Usp. 21 (1978) 277 u. Bericht der Novosibirskgruppe: CERN 77-08, April 1977
6 F.T. Cole and F.E. Mills, Ann. Rev. Nucl. Part. Sci. 1981, 31:295-335

7. S. Martin, W. Schott, C.-A. Wiedner, Workshop on Electron Cooling, Bad Honnef, May 1982, Jül-Spez-159, Juli 1982, KFA Jülich
8. G. Berg et al., Studie zum Bau eines kombinierten Kühler-Synchrotron-Rings an der KFA Jülich, Jül-Spez-242, Februar 1984
9. S.A. Martin, A. Hardt, J. Meissburger, G.P.A. Berg, U. Hacker, W. Hürlimann, J.G.M. Römer, T. Sagefka, A. Retz, O.W.B. Schult, K.L. Brown, K. Halbach, Nucl. Instr. Meth. 214 (1983) 281
10. Fermilab Electron Cooling Experiment, Internal Report, August 1978
11. W. Hardt, Ultraslow Extraction out of LEAR, $\bar{p}p$ LEAR Note 98, and P. Lefevre, Lecture, given at the CERN ACCELERATOR SCHOOL 1983, Genf, Okt. 1983