SULEICKA: A PROPOSAL FOR A SUPERCONDUCTING LIGHT ION CYCLOTRON AT KARLSRUHE

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Abstract. - This study shows, that the "old" Karlsruhe Isochronous Cyclotron equipped with a ECR-Type source is well suited as an injector for a superconducting sector cyclotron to produce light ions (p, d, α, $^{6}Li^{3+}$, $^{10}B^{5+}$, $^{14}N^{7+}$, $^{16}O^{8+}$ and $^{20}Ne^{10+}$) with an energy of up to 500 MeV per nucleon. SULEICKA is a separated-sector cyclotron with a fourfold symmetry which can be operated using superconducting coils at the same mean magnetic field as the injector.

1. Introduction. - The Karlsruhe Isochronous Cyclotron provides light ions with $e/m = \frac{1}{2}$ with a fixed energy of 26 MeV per nucleon. At the present we have started a study with the aim to show, that it is not only technically feasible to build a post accelerator for this very efficient injector configuration, but that with the help of superconducting technology it is also economically feasible. At the moment it seems most likely that the final choice will be a single stage superconducting sector cyclotron with a maximum energy of 500 MeV/N.

Such a machine could open up a whole field of nuclear physics beyond the mesonic domain (see navigation chart in fig. 1) and could also be used to study in the transition region between microscopic (protons) and macroscopic ($A^{1/3} \gg 1$ for the projectils) collision phenomena at energies which are not yet available at other facilities.

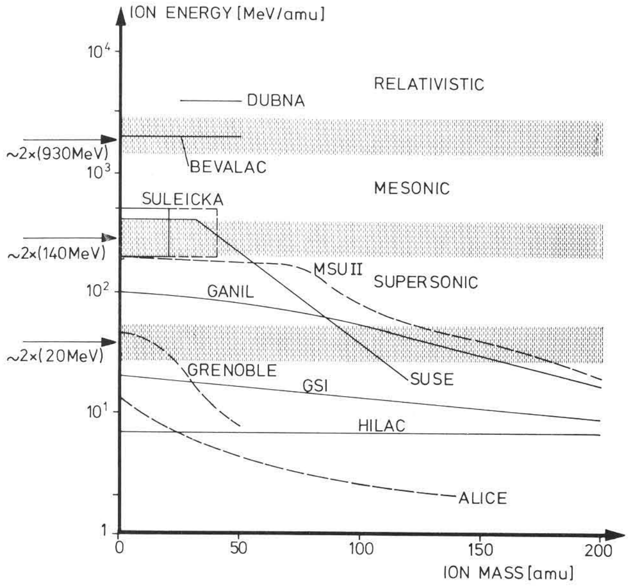

Fig. 1: Energy vs mass characteristic for SULEICKA and other large facilities. In crossing each of the regions defined by the shaded bands, we can be confident that the underlying physics will change.

Another fascinating application of high energy light ions lies in the field of radiotherapy and isotope diagnostics. The advantages of light ions for radiotherapy in the energy range of 400-600 MeV/N has been discussed at the preceeding cyclotron conference[7]. Isotope diagnostics are based on the fact that some product fragments of high energy ^{12}C; ^{14}N; ^{16}O and ^{20}Ne beams hitting a target are positron emitters (^{11}C; ^{13}N; ^{15}O; ^{19}Ne). In this way one can produce monoenergetic beams of positron-emitting isotopes. These isotopes can be used, for example, to measure the depth distribution of light ions in tissue before therapy.

ION	E/A [MeV/u]	ε [π mm mrad]	Δt_{fwhm} [psec]	$\Delta E/E_{fwhm}$	I [μA]	typ of ion source
H_2^+	200-500	2 axial 1 radial	<500	5×10^{-4}	20	internal Penning
d;d↑					20	internal Penning Lambshift
$^{4}He^{2+}$					10	internal Penning
$^{6}Li^{3+}$					0.2	external Penning
$^{10}B^{5+}$					0.1	ECR-HISKA
$^{12}C^{6+}$					0.1	ECR-HISKA
$^{14}N^{7+}$					0.1	ECR-HISKA
$^{16}O^{8+}$					0.1	ECR-HISKA
$^{20}Ne^{10+}$					(?)	ECR-HISKA
$^{24}Mg^{12+}$; $^{28}Si^{14+}$						future ECR* or
$^{32}S^{16+}$					(?)	EBIS-sources
$^{36}Ar^{18+}$; $^{40}Ca^{20+}$						

Fig. 2: Expected beam quality and extracted currents for SULEICKA.

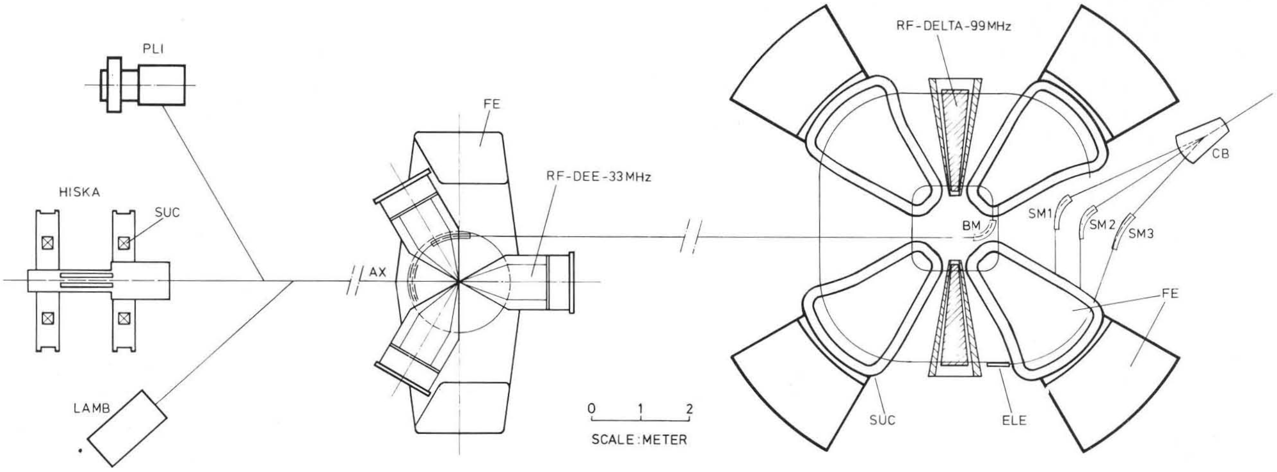

Fig. 3: Schematic view of the accelerating complex "SULEICKA".
HISKA = Heavy Ion Source Karlsruhe; LAMB = Lambshift Ion Source; PLI = Penning Ion Source for $^{6}Li^{3+}$*-Ions; AX = Axial Injection Line; FE = Iron; SUC = Superconduction Coils; ELE = Electrostatic Extraction Element; SM1 - SM3 = Septum Magnets; CB = Combination Magnet; RF = Radiofrequency System; BM = Bending Magnets.*

2. General Description of SULEICKA. - The aim of our studies is to propose a simple postaccelerator for the Karlsruhe Isochronous Cyclotron to boost all ions with a charge to mass ration of 1:2 (deuteron-like ions) up to an energy of 500 MeV/N. In view of lower investment costs and simplicity in operation we have not tried to design a broad-banded machine. Therefore SULEICKA is much more similar to medium energy proton accelerators than to special heavy-ion machines.

Figure 2 summerizes the design goals for nuclear physics purposes in terms of beam quality parameters. The intensity values listed for the extracted beams in the energy range between 200 and 500 MeV per nucleon are extrapolated currents from our experience with the injector. The currents provided by the ECR-source HISKA [1] are based on conservative numbers from R. Geller [2] and a 10 % transparency from the external ion source to the experimental area. The numbers for phase width and transversal emittances are based on experimental values known for the injector, taking into acount the phase compression effect and the momentum gain in SULEICKA.

In figure 3 a schematic representation of the accelerating complex is shown, consisting of:

a) External ion sources which are connected by a low energy (10 keV) beam transport and axial injection system to the "old" Karlsruhe Isochronous Cyclotron.

b) A fixed frequency cyclotron for the first stage acceleration delivering an energy of 26 MeV/N for deuteron like ions. The beam has to be appropriately transported to the second cyclotron to get the energy dispersion and emittance pattern needed for the first trajectory of SULEICKA.

c) SULEICKA is made of four 30° sectors. In order to maintain the high mean field (14.7 KG) of the injector sector magnets with superconducting coils are proposed. In this case matching the two cyclotrons is easy because the orbit frequencies are the same. Other advantages of the high hill field (44.1 KG) are:
Compared to conventional magnets the size of the machine is halved. One obtaines a large flutter ($F^2 > 4$) which aide in focussing of the beam.

The accelerating system consists of two SIN-style Delta resonators operating at a fixed frequency of 99 MHz. Because of the high injection energy the mean injection radius of 105 cm is rather large compared to other sector cyclotrons (GANIL: 75 cm; VICKSI: 45 cm; SUSE: 40 cm). Variable energy extraction is planned to be realized by a radially adjustable electrostatic septum combined with a radially and azimuthally adjustable superconducting septum magnet (max. field strength 35 KG). In order to transport the variable energy beams in a common beam guiding system they will be combined in an "inverse" switching magnet. Extraction will be facilitated by a rather large turn separation of 2.3 mm (at 500 MeV/N, without a coherent betatron oscillation). In this way the energy of the extracted beam can be varied over a large range without changing the magnetic field and the frequency.

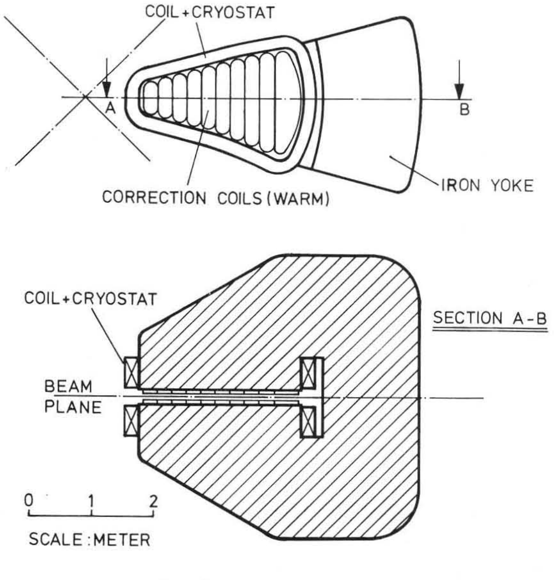

Fig. 4: Superconducting magnet design for SULEICKA.

3. Magnet- and acceleration system. - The top- and side-view of one sector magnet is shown in fig. 4. The main problem in the design of the magnetic field for high energy cyclotrons is the rapid rise of the average field due the relation $\bar{B} = \gamma B_c$. For SULEICKA γ rises from 1.027 to 1.261. This problem can be solved with straight radial sectors by a large number of superconducting correction coils as in the SUSE-project 3) or as we propose for SULEICKA, by increasing the azimuthal width of the magnet with increasing radius. First calculations show that a rather precise homogenous field can be produced and that the fine tuning of the field can be done by warm correction coils mounted onto the pole faces. Because sufficient space is available in the central region of SULEICKA and the field strength is relatively low (44.1 KG), it is possible to arrange the superconducting coils in separate cryostats above and below the median plain.

The radiofrequency to be used is fixed by the following conditions: To get single turn extraction and a high beam pulse compression, the accelerating voltage is expected to increase with a positive gradient from about 1 MV energy gain to 2 MV. Recently, N. Schmid from SIN 4) has demonstrated that this can be realized by using a half-wave resonator with a Delta-shaped resonant line. The RF power needed to run such cavities at 500 kV will be approximately 500 KW. This power level at 99 MHz is not at all trivial. In the frame of the SNQ project study at Karlsruhe 5) however, a tetrode amplifier (108 MHz) in this power range has been studied with the result that it should be feasible.

4. Focussing. - In order to get some ideas on the focussing problems of SULEICKA we have put our faith in the hard edge approximation and used the expressions for v_z and v_r derived by G. Schatz 6) for a separated sector cyclotron with spiral magnets and uniform hill field. The results is shown in figure 5.

5. References

1) V. Bechtold et al.,(D) in these proceedings

2) R. Geller, IEEE Trans. Nucl. Sci. NS 26, No. 2, 2120 (1979)

3) H. Daniel et al., IEEE Trans. Nucl. Sci. NS 26, No. 3, 3721 (1979)

4) N. Schmid, IEEE Trans. Nucl. Sci. NS 26, No. 2, 2194 (1979)

5) I.E. Vetter, The Basic Concept of the SNQ Linear Accelerator, KFK 3180 (1981)

6) G. Schatz, Nucl. Instr. Meth. 72, 29 (1969)

7) G.U. Behrsing et al., IEEE Trans. Nucl. Sci. NS 26, No. 2, 2061 (1979)

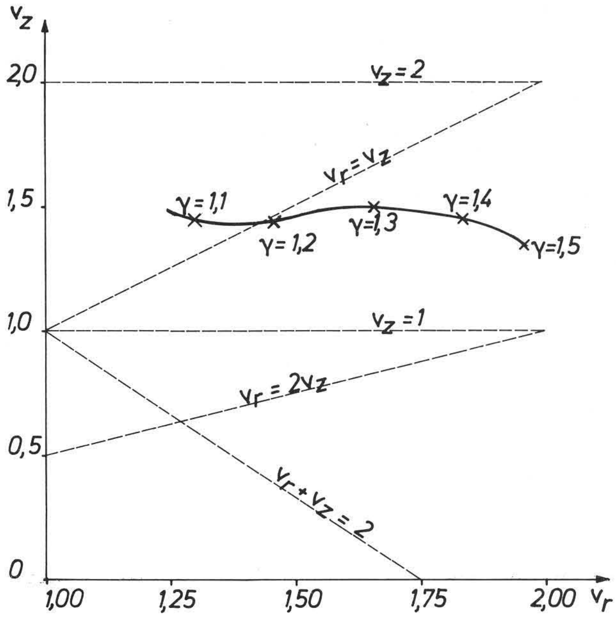

Fig. 5: Focussing frequencies for SULEICKA in the hard edge approximation.

final energy of SULEICKA		500 MeV/u
injection energy		26 MeV/u
energy gain		~ 20
injection radius		1.05 m
extraction radius	(500 MeV/u)	3.5 m
	(300 MeV/u)	2.85 m
	(200 MeV/u)	2.2 m
turn separation	(500 MeV/u)	2.3 mm*
number of sectors		4 x 30°
center isochronous field		14.79 kG
increase in azimutal width		12°
maximum spiral angle		10°**
magnet gap		60 mm
number of correction coils (warm)		8 x 12
estimate of magnet weight		240 tons
orbit frequency injector		11 MHz
orbit frequency SULEICKA		11 MHz
RF frequency injector		33 MHz (3rd harmonic)
RF frequency SULEICKA		99 MHz (9th harmonic)
number of cavities		2 x 20°
peak energy gain/turn injection		1.0 MV
extraction		2.0 MV
phase width injector		1 nsec (12°)
SULEICKA		< 0.5 nsec (18°)
number of turns		~ 300
RF-power per cavity		~ 500 KW

* by adding a coherent oscillation this can be increased by a factor of two

** by adding iron in parallel to the edge of the hill one may increase the flutter by 30%, so that spiral can be avoided.

Fig. 6: Preliminary parameters for SULEICKA.