MULTIPURPOSE SUPERCONDUCTING CYCLOTRON

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Summary

This paper reviews main design features of a compact superconducting injector cyclotron,which equipped with an axial injection line and ECR ion source should be able to accelerate light ions,up to Ne,to energies higher than 25 A MeV,heaviest ions to energies which admit additional stripping at the entrance of booster cyclotron;p,d and He particles to energies of focusing limit.

Introduction

The accelerator complex composed of two cyclotrons and ECR ion source is planned to be the principal facility for the accelerator research project at the Boris Kidrich Institute.[1]This paper reviews the results of project study whose goals were to work out the conceptual design features of a compact superconducting injector cyclotron which,equipped with an axial injection line and ECR ion source,should be able to satisfy the requirements for a multipurpose machine.The project study,together with the construction of the prototype of the main coil sections are funded by SRS scientific funds.

In case of an ordinary AVF cyclotron the concerned feromagnetic structure has a dominant role in the production of average magnetic field and field modulation for axial focusing.The intensities of contributions of the concerned feromagnetic structure to the actual magnetic field are strongly influenced by gap to pole radius ratio.An increasing of the pole radius does not only increase the bending power of the cyclotron magnet through a r^2 dependence but,as well as,by simultaneous increasing of the maximum achievable average magnetic field.By properly chosen gap to pole radius ratio,it is possible to produce the approximatly equal bending and focusing limits of the cyclotron magnet,in the adequatly chosen range of the cyclotron magnet pole radii.When the conventional coil is replaced by the superconducting coil,as in the case of superconducting cyclotrons of the first generation,the bending limit becomes considerably higher than focusing limit,the latter then becoming an operating limit for energies/nucleon in the region of light nuclei.

When the pole radius of the cyclotron magnet of an ordinary AVF cyclotron is decreased below some critical value,the bending limit is reduced below focusing limit of cyclotron magnet,for the reasons mentioned above.Thus the operating limit of an ordinary AVF cyclotron with small pole radius becomes determined rather by bending limit,than by focusing limit of the cyclotron magnet.Therefore,it can be expected that the use of the superconducting cyclotrons,which can produce a sufficiently high bending limit even at a small cyclotron magnet pole radius,could considerably improve the various aspects of research activities, covered now,in the range of smaller K numbers,exclusively by the ordinary AVF cyclotrons.

Cyclotron Magnet

The basic structure of the cyclotron magnet involves,as in the case of the other superconducting cyclotrons of the first generation[2-5],the solenoidal superconducting coil housed in pill-box type yoke

The choice of basic goals in this case strongly determines the coil,cryostat and iron structure design. The maximum ionic charge vs. atomic number for VINIS ECR ion source is shown in fig.1.The expected beam intensity is of order of 100 pμA for lower ionic charge and 0.5 pμA for higher ionic charge,with normalized emittance approximatly of about 5 mm mrad.The average charge of ion beam expected to be obtained after passing the stripper foil at the entrance of the booster cyclotron is given by relation:

$$Z_{eff}=Z(1-\exp-(137(1-\gamma^{-2})^{1/2}/Z^{.55}))$$

The simple calculation shows,that in order to obtain a factor of order of 1.5 for additional stripping for heaviest ions,K number of the injector cyclotron must be of order of K=100 MeV.In this case the beam component with most probable charge state for heaviest ion species has sufficiently high intensity and additional stripping has sense to be performed.The cyclotron designed to have bending power of K=100 MeV, should be able to accelerate the fully stripped ions up the Ar,to energies of 25 A MeV,if the focusing limit is provided to be $K_f \geq 50$ MeV.

The research is being carried out for design which minimizes the size and cost of a machine.The considerations of various configurations at which the value of $K_f=50$ MeV could be obtained for a cyclotron designed to have a maximum bending power K=100 MeV,led as to a conclusion that an extraction radius of 28 cm,pole radius of 30 cm and a maximum average field value at extraction radius of 5.15 T has to be used.Once specifying the basic geometry the conditions for obtaining the required focusing power at chosen hill gap and field symmetry,can be defined.The estimated maximum focusing power for 3-sector machine,sector angles of approximatly 60^o,$\tan\gamma_{max}=\pi/3$ and hill gap $g_h=6.4$cm is given together with the other main parameters in table 1.

The considerations of conditions for matching the requirements for multipurpose compact cyclotron pointed out the nature of design compromise,which we must accept in coil and iron structure design.Firstly,the optimization of the coil design was performed to obtain the minimum volume factor and coil parameters necessary to isohronise the given maximum field value at the extraction radius,then the coil,cryostat and iron configurations listed in tables 2 and 3 ,are specified. The coil sections are provided to be of stabilized NbTi superconductor immersed in liquid helium at atmospheric pressure.The main coil is split into two independently powered sections,that are used to shape the required field profile to within a small difference.The trimm coils wrapped around the pole tips,should be able to compensate the remaining difference field.The value of the coil splitting factor was deduced from the requirement,that a nesessary magnetic field for proton acceleration would have to be produced from the air core form factor of the coil sections,that are closer to the median plane.

TABLE 1

Main machine parameters

Ion source	PIG and ECR ion source equipped with an axial injection line
Bending constant	K=100 MeV
Focusing constant	K_f=53 MeV
Main coil	2x2 identical superconducting coil sections
Pole radius	r_o=30 cm
Extraction radius	r_x=28 cm

TABLE 2

Main coil parameters

Internal radius	r_1=37 cm
Outer radius	r_2=49 cm
Coil total height	H=4x14 cm=56 cm
Coil splitting	2x2 identical sections
Maximum distance from median plane	h_{MP}=4.5 cm
Height of one section	h_s=14 cm
Layers/section	n_L =2x5=10
Turns/pancake	n_t=2x30=60
Maximum overal current density	j_c=4 kA/cm^2
Amper-turns at 4kA/cm^2	NI=2.66x10^{6}At
Conductor	monolitic NbTi
Overall Cu/SC	20:1
Vacuum tank iner radius	30.5 cm
Vacuum tank outer radius	65 cm

In order to start the coil construction indepedently of cryostat and to chek the results of the winding procedure during the period of coil fabrication, the double pancake technique for coil winding was chosen.The internal coil structure should be of well known organization,with an inserted-type of the superconducting cable,mylar ribbon used for turn to turn isolation and fiberglass strips as the isolation between the layers.The fast iron field fall-off,allows that an average current density of 4 kA/cm^2 in main coil can be used.At this current density the superconducting coil,together with iron configuration, provide at the extraction radius a maximum field of 5.15 T.

The yoke will be cylindrical with removable sections at the top and bottom for acces to the gap. The designed field value in the return yoke is below 1.7 T,determining a weight of the iron structure to be of the order of Q=22 tons.Flutter in the magnet is provided by 3 spiral saturated steel sectors at a maximum valey gap to hill gap ratio of 5.

TABLE 3

Iron structure parameters

Pole radius	r_o=30 cm
Yoke height	h_Y=169 cm
Yoke outer diametar	d_Y=168 cm
Minimum hill gap	g_h=6.4 cm
Maximum valley gap	g_v=32 cm
Yoke weight	Q =22 t

Acceleration system and extraction

Three accelerating electrodes are provided,one in each valley.The electrodes are spiral shaped with an azimuthal extent of about 60°.RF system design should be based on the usage of high power RF transmitters,with frequencies in the FM band(110 MHz) and 200 MHz range[6].Runing protons in 110 MHz second harmonic requires the values of center field at which the limiting phenomena do not come seriously into play. An energy gain per turn of 0.5 MeV/turn can be in this case obtained at a RF voltage peak value of 100 keV. An extraction line,composed of electrostatic deflector(140 kV/cm) and magnetic channels,which takes of about 120° of azimuthal span is provided as the basic feature of the extraction system.

Since the three-dee cyclotron can operate with a variety of values for harmonic number h,it can accelerate a wide spectrum of ion species even with a fixed oscillator frequency.An effective charge Z_{eff},which could be obtained at the entrance of booster cyclotron in a fixed frequency mode(f=110 Mhz,h=2 and h=3n) is shown,together with the design goals of VINIS ECR ion source,in fig.1.The bending and focusing operating limits for K-100 multipurpose superconducting cyclotron are given in fig.2,while the magnet design and the details of coil and coil section design are shown in figs. 3 and 4.

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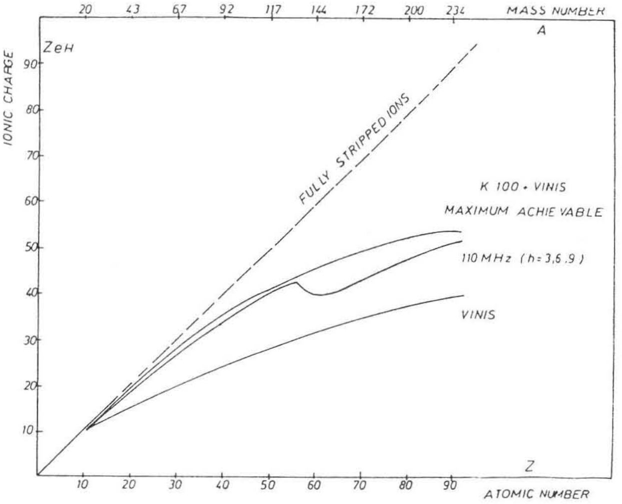

Fig. 1

Ionic charge Z_{eff} vs. atomic number Z

a.) Fully stripped ions

b.) Maximum achievable Z_{eff} after stripping at the entrance of booster cyclotron, when a variable oscillator frequency for K-100 + VINIS ECR ion source is used

c.) Maximum achievable Z_{eff}, when a fixed 110 MHz oscillator frequency is used (h=3,6,9)

d.) VINIS design goals

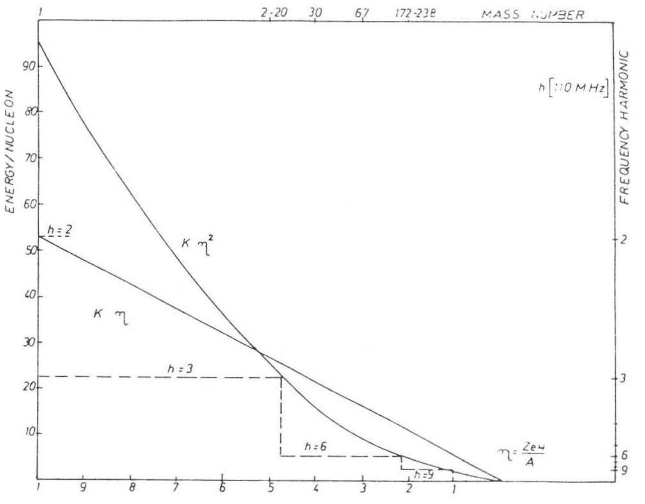

Fig. 2

Energy /nucleon bending and focusing operating limits for K-100 superconducting injector cyclotron.

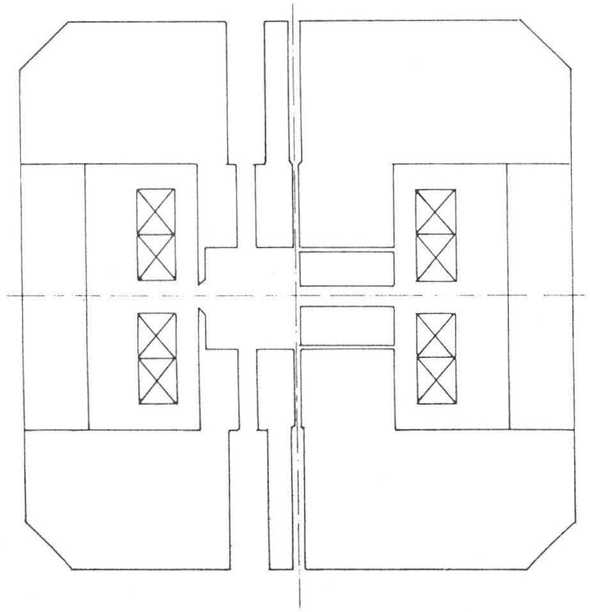

Fig. 3

Magnet design of K-100 superconducting injector cyclotron.

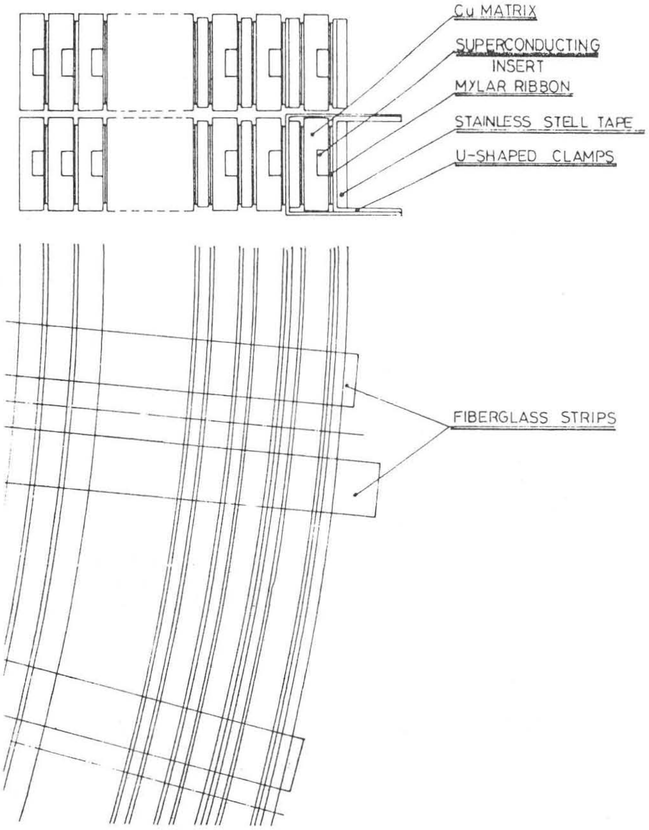

Fig. 4

Details of the main coil and the coil sections design.