Design Studies of Superconducting Heavy Ion Cyclotrons

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Superconducting main coils give compact much less expensive structures for heavy ion cyclotrons, as has been pointed out by the group at Chalk River.[1] In a series of studies we have evolved a design for a cyclotron with a 400 MeV energy parameter which would cost under $2,000,000. The performance characteristics of this cyclotron are shown in Figure 1 (the curves labeled 400s) with both 13 and 25 MV tandems as injectors and with both gas and foil stripping in the tandem terminal. With either of these injectors the cyclotron produces reaction energies over the entire periodic table.

Cyclotrons of this type are characterized by both a bending limit and a focusing limit. Figure 2 shows the limiting energies for various values of Z/A for both our design and for the design suggested at Chalk River. Our bending limit is somewhat lower than that of Chalk River but the stronger focusing makes the useful maximum energy higher for Z/A>0.17.

A mechanical drawing of this cyclotron is shown in Figure 3. The main coil and pole tip are arranged to give a relatively sharp field edge which greatly eases the extraction problem as compared with earlier designs. Extraction with conventional electric and magnetic elements is feasible. We are however also studying the use of superconducting shields as utilized at SLAC.[2] Such shields are very inexpensive since the refrigeration would be available from the coil cooling system and, more importantly, they would completely eliminate the strong fringe field defocusing which makes the optical design of a normal cyclotron extraction system very difficult.

A proposal has recently been submitted for a prototype magnet study for such a cyclotron.[3] A much more complete description of these studies is contained therein. Continuing effort on these studies is now concerned with calculations of realistic trim coil currents and calculations of the effect of spiral dees on the radial focusing oscillation.

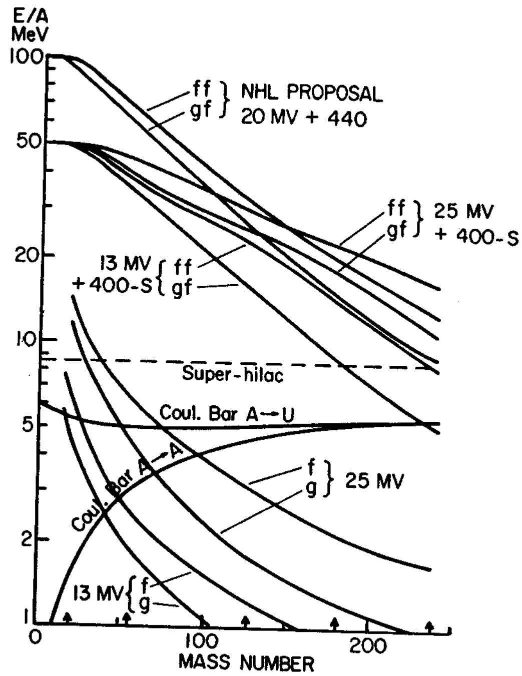


FIG. 1.--Energy per nucleon for various accelerators and accelerator combinations, compared with the estimated Coulomb barrier. Labels "13 MV" etc. indicate assumed terminal voltages of tandems, "g" and "f" indicate gas or foil stripping in the tandem terminal. The NHL proposal is reference 4.

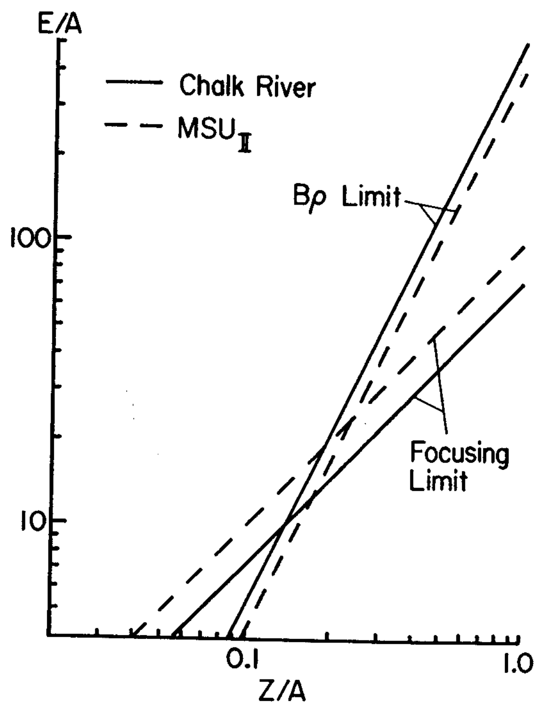


FIG. 2.--Energy limits from Bρ and from focusing for the Chalk River design, reference 1, and for the MSU design. The useful operating region is at the lower right (the region below both the Bρ and the focusing limits). The stronger focusing of the MSU-II design gives higher energy over most of the Z/A range (Z/A>.17).

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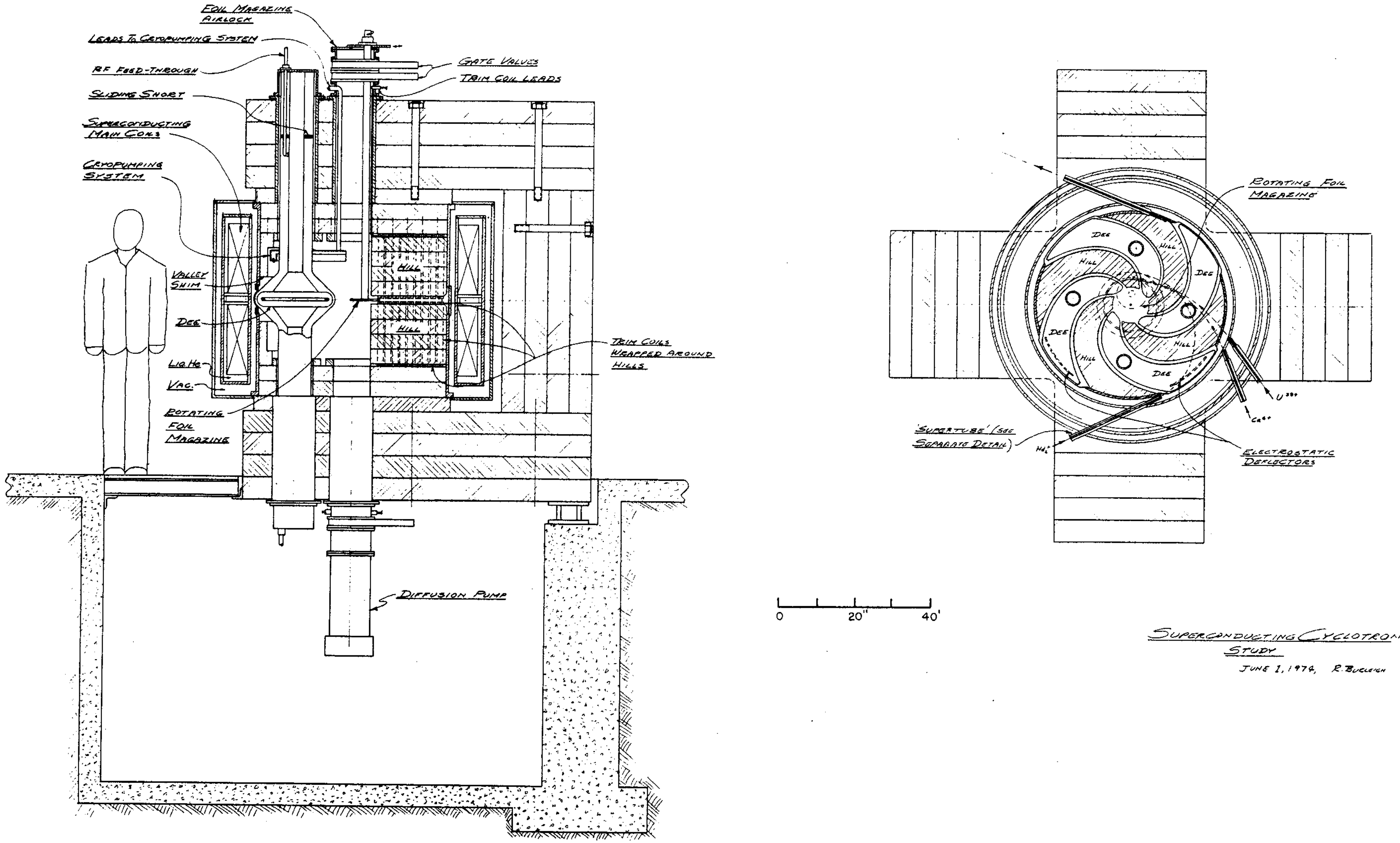


FIG. 3.--An MSU design for a K=400 MeV superconducting cyclotron. The pole tip spiral provides focusing adequate for 100 MeV protons. Four spiral dees are mounted on individual vertical stems. The cryostat extends thru the median plane with "supertube" penetrations (per ref. 2) for injection and extraction. There is a full yoke.

Orbit Properties of Ions in a Migma Fusion Device

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During the past few years, a group at Rutgers headed by B. C. Maglich has been working on the development of a practical fusion power source through the application of acclerator and storage ring concepts. A detailed report on this work has been presented in a paper entitled "The Migma Principle of Controlled Fusion," in which Maglich describes the theory and design of the "Migma Cell," a complete reactor unit having an estimated power output between 10mW and 10 W.[1] The power output is limited by space charge effects, and a recently proposed solution to this problem has led Maglich to conclude that a Migma Cell 40 cm in diameter might produce 0.1 megawatts.[2]

The design of a Migma device requires, first of all, accurate information regarding the dependence of basic orbit properties on magnetic field parameters and on ion energy. These properties include, in particular, the geometry of the orbits and the frequency $\nu_z$ of the vertical oscillations. Using equilibrium orbit and transfer matrix techniques, we have developed a computer code which, for a given magnetic field, calculates all the important properties of the median plane orbits and of the vertical oscillations as a function of momentum. The structure of this code together with some preliminary results have been described in a paper entitled "Basic Orbit Properties of Ions in a Migma Fusion Device," which we have already submitted for publication.[3]

The most important results we have obtained concern vertical focusing. These results show that inherent alternating-gradient effects increase the vertical focusing, but beyond a critical momentum value, the vertical oscillations become unstable because of over-focusing. This behavior is displayed in Fig. 1, where the focusing frequency $\nu_z$ is plotted as a function of momentum for the same magnetic field as used by Maglich: $B_z(r) = B_o(1-r^2/R_o^2)$. As momentum variable, we use $p = mvc/qB_oR_o$, so that the results will apply to any ion and for any values of $B_o$ and $R_o$.

Maglich uses the value: $\nu_z = p\sqrt{2}$, which is shown by the broken line in Fig. 1. Evidently, the values of $\nu_z$ increase faster than $p\sqrt{2}$, and reach the value $\nu_z = 1/2$ at $p = 0.215$. Above this critical p value, the vertical oscillations become unstable, and the resultant complex value of $\nu_z$ is given by: $\nu_z = 0.5 \pm i\nu_z^*$. The values of $\nu_z^*$ are also shown in Fig. 1.

For the sake of clarity, Fig. 1 does not show the rapid variation in $\nu_z$ in the narrow range between $p = 0.253$ and $p = 0.272$, the maximum momentum which can be confined in the median plane of this field. Between $p = 0.253$ and 0.268, the value of $\nu_z$ becomes real again and rises from $\nu_z = 0.5$ to 1.0; above $p = 0.268$, the vertical oscillations are again unstable.

In his design of the Migma Cell, Maglich uses 2.2 MeV deuterons in a field with $B_o$=200 kG and $R_o$=5.6 cm.[1] In terms of our momentum variable, these parameters correspond to p=0.27, so that according to our results, Maglich is proposing to operate in the region of vertical instability for motion close to the median plane. This means that the vertical focusing reported by Maglich is centered not on the median plane, but rather on a three dimensional closed orbit associated with some nonlinear coupling resonance. A proper evaluation of the consequences of operating a Migma device under such conditions will require further investigation.

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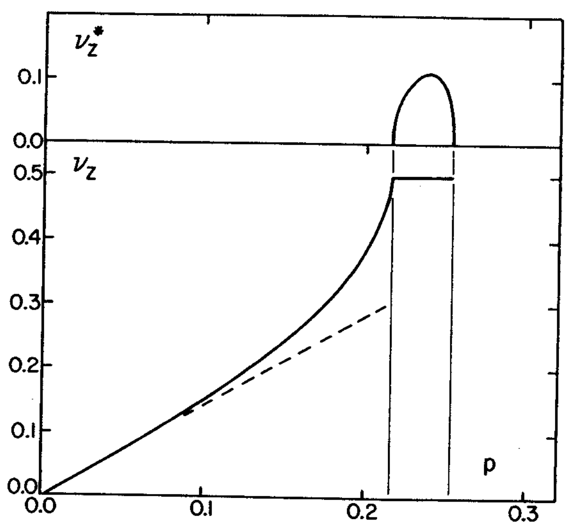


Figure 1.