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A RAPID CYCLING SYNCHROTRON MAGNET WITH SEPARATE AC AND DC CIRCUITS*

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Abstract

In present rapid cycling synchrotron magnets ac and dc currents flow in the same coil to give the desired field. The circuit reactance is made zero at dc and the operating frequency by running the magnet in series with an external parallel resonant LC current. We propose to return the ac flux in a gap next to the synchrotron. The dc coil encloses the ac magnetic circuit and thus links no ac flux. A shorted turn between the dc coil and ac flux enhances the separation of the two circuits. Several interesting developments are possible. The dc coil could be a stable superconductor to save power. The ac flux return gap could be identical with the synchrotron gap and contain a second synchrotron. This would double the output of the system. If the return flux gap were used for a booster, the ac coil power could be greatly reduced or radiation hardening of the ac coil could be simplified.

Magnets with Separate AC and DC Circuits

In existing rapid cycling synchrotrons, the magnet circuit is made resistive at dc and at the operating frequency by putting the magnets in series with a parallel LC circuit. The large cost, in some cases, of these external components made us look for an alternate system.

In the system presented here an external inductance or choke is not required. The magnet has two gaps. The ac flux makes a loop within the magnet, up one gap, across the top yoke, down the other gap, and back in the bottom yoke. Both gaps are driven by ac coils and operate as two inductances in series. By putting this inductance in series with an external condenser the ac circuit is made resistive at operating frequency.

The ac magnet is placed inside of a dc magnet which furnishes the average synchrotron field. The separation of the ac and dc circuits can be enhanced by a shorted turn inside of the dc coil.

A small test magnet was built incorporating these principles and offered no surprises.

Figs. 2 through 5 show some variations of this scheme. Fig. 2 shows a synchrotron and choke. The choke gap is wider because it is somewhat less expensive to operate the choke at a lower ac field. For a modest additional cost both gaps can be made the same. In this case, both gaps can be used for synchrotrons, as is suggested in Fig. 3. When beam is being accelerated in one synchrotron the other is returning to low field. Thus beam is delivered at twice the ac frequency. Both synchrotrons need not perform the same function but both carry the same ac flux. Fig. 4 suggests using one side as a booster and the other side as a high energy synchrotron. When the booster reaches peak field the synchrotron is at minimum field. The magnet is designed so that these two fields are equal and the beam can be transferred from one machine to the other. Since the synchrotron gap can be smaller and the field change is smaller, the ac A turns are small in this arrangement. This should simplify radiation hardening of the ac coil which might be a few large conductors. The dc coil can, of course, be metal jacketed mineral insulated conductor soldered into a monolith. Finally, Fig. 5 shows an arrangement where the dc A turns are used for a high energy storage ring. Some of the dc A turns might also be used for an injection storage ring which might improve the injection process. Fig. 6 gives the meanings of the shadings and the scale of the drawings.

Cost

For a quick look at the cost problem, the over-simplified designs shown in Figs. 1 through 6 were used. The cost factors are given in Table I. All costs are based on 20 GeV protons. The injection energy is 200 MeV and the gap for injection is 0.25 m wide by 0.15 m high. The costs were minimized by varying the available parameters. It is clear that only the most general conclusions are valid. The costs are given in Table II.

The cost of the conventional separate magnet and choke, the combined magnet and choke, and the double synchrotron is about the same. If two synchrotrons are required then the double synchrotron, Fig. 3, is a money saver. There is a real cost advantage where one side is used as a booster and the other side as a synchrotron, Figs. 4 and 5.

Summary

Returning the ac flux within the synchrotron magnet has good and bad points. Of course some quite new structures are possible. Some new problems are:

1. the return flux coil is exposed to radiation,
2. the ac flux in one direction is equal to the ac flux in the other direction, and the dc A turns are the same on both gaps. This imposes new tolerances and restricts the design parameters, and
3. it is difficult to incorporate this system into a separate function lattice.

Some advantages are:

1. possible cost savings,
2. separate ac and dc fields permit the use of fully stabilized superconductors in the dc circuit,
3. radiation hardening of the magnet might be simplified, and
4. where a very high pulse rate is required two synchrotron magnets for the price of one might be a real advantage.

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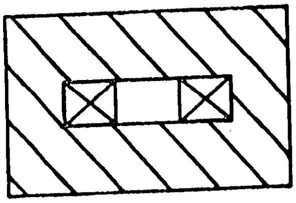
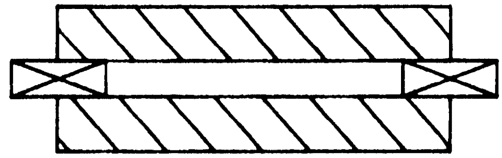


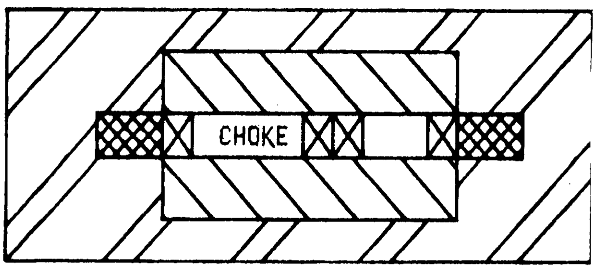
YOKE LENGTH = 4.006 m.

FIGURE 1.1 SYNCHROTRON MAGNET



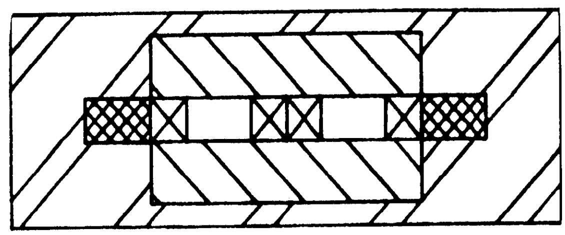
THE VERTICAL YOKES ARE AT THE ENDS
YOKE LENGTH = 1.513 m.

FIGURE 1.2 SEPARATE CHOKE



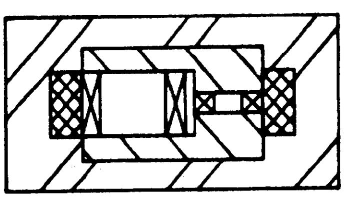
YOKE LENGTH = 4.006 m.

FIGURE 2 CHOKE AND SYNCHROTRON



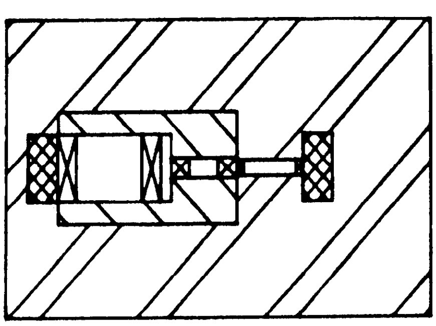
YOKE LENGTH = 4.006 m.

FIGURE 3 DOUBLE SYNCHROTRON



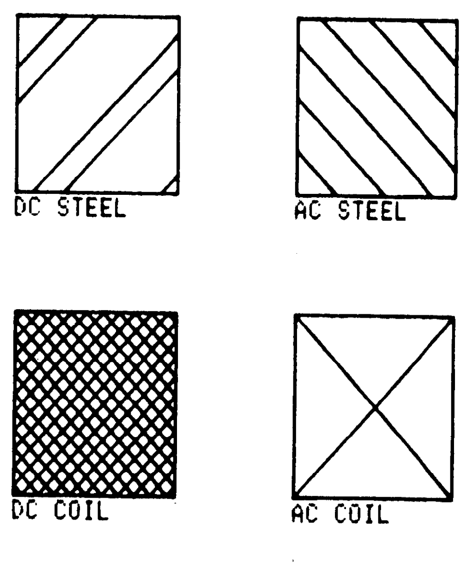
YOKE LENGTH = 4.006 m.

FIGURE 4 BOOSTER AND SYNCHROTRON



YOKE LENGTH = 4.006 m.

FIGURE 5 BOOSTER, SYNCHROTRON, AND STORAGE RING



SCALE = 0.5 m.

FIGURE 6 SHADINGS AND SCALE

Table I - Cost Factors

dc power capital cost and some operation	0.6	\$/W
ac power capital cost and some operation	0.6	\$/W
dc coil	70 K	\$/(m^3 copper)
ac coil	100 K	\$/(m^3 copper)
dc steel fabricated	5 K	\$/m^3
ac steel fabricated	20 K	\$/m^3
condensers for tuning	0.4	\$/J

Table II - Costs

Costs in \$M	Figure	Steel	DC coil & power	Coil	AC coil & power	Condensers	Total
Separate Synchrotron	1.1	2.7	4.8*	1.1	2.1*		
and Choke	1.2	2.0	1.4*	1.1	0.4*		
Total		4.6	6.2*	2.1	2.5*	2.8	18
Combined Synchrotron and Choke	2	3.8	4.9	---	6.1	1.8	17
Double Synchrotron	3	3.3	4.9	---	7.4	2.8	18
Booster and Synchrotron	4	1.3	2.5	---	2.7	0.4	7
Booster, Synchrotron and Storage Ring	5	2.4	2.9	---	2.7	0.4	8

*Coil cost not included.