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DUAL-APERTURE DIPOLE WITH 2ND HARMONIC*

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Summary

Two rapid-cycling accelerator rings are arranged in one magnet-iron structure. There are two sets of coils, one located in each ring, which are connected in series and excited with a first-harmonic frequency. One dc bias coil and one second-harmonic coil are common to both rings. The second harmonic reduces $\dot{B}$ during acceleration by 33% as compared to single-frequency operation. The features of this economical arrangement are described and compared to more-conventional systems. This system is especially suitable for combined-function magnets.

Introduction

Two synchrotrons with their magnet guide fields 180° out of phase may share one power supply to reduce construction and operating costs. These synchrotrons may have two separate but identical rings in order to reduce the beam intensity in each by half as compared to only one conventional synchrotron; or one ring may be a booster and inject into the second ring. Figure 1 shows two separate rings sharing one power supply.

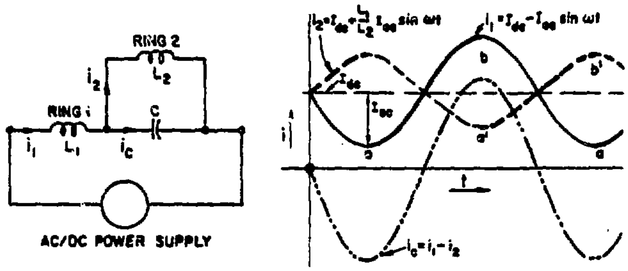

Fig. 1. Resonant circuit for two rings having one power supply in common.

With the two rings 180° out of phase their energy can be transferred from one to the other via a resonant capacitor bank (one ring acts as a choke for the other as in a conventional biased circuit); this eliminates the costs for chokes and only one capacitor bank is required. The circuit currents are:

$$i_1 = I_{dc} - I_{ac} \sin \omega t \qquad (1)$$

$$i_2 = I_{dc} + \frac{L_1}{L_2} I_{ac} \sin \omega t \qquad (2)$$

$$i_c = i_1 - i_2 = -\frac{L_1 + L_2}{L_2} I_{ac} \sin \omega t \qquad (3)$$

$$\omega = \left(\frac{L_1 + L_2}{L_1 L_2 C}\right)^{1/2} . \qquad (4)$$

Ring 1 accelerates between times a and b; ring 2 between times a' and b'.

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If both rings are identical, $L_1 = L_2 = L$, the circuit currents are:

$$i_1 = I_{dc} - I_{ac} \sin \omega t \qquad (1)$$

$$i_2 = I_{dc} + I_{ac} \sin \omega t \qquad (2')$$

$$i_c = i_1 - i_2 = -2 I_{ac} \sin \omega t \qquad (3')$$

$$\omega = \left(\frac{2}{LC}\right)^{1/2} . \qquad (4')$$

Probably the least expensive two-ring circuit may be the one illustrated in Fig. 2. This magnet

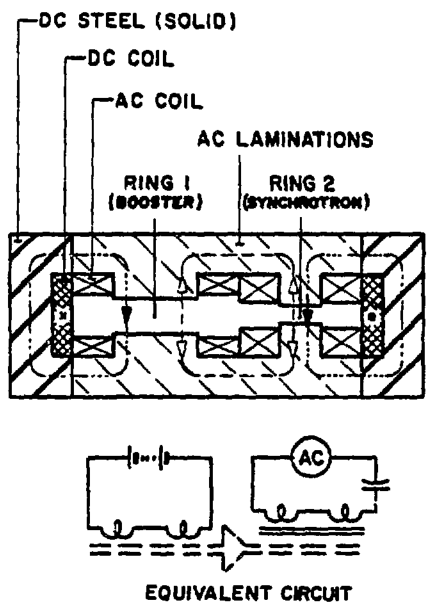

Fig. 2. Two rings utilizing one core structure.

configuration is a modification of the one described in Reference 1, which places an ac magnet (having only top and bottom yokes)[2] inside a dc magnet. Like the circuit described above, it does not require a separate choke. In addition, it has the following desirable features:

1. The inductances of the two rings are connected in series. Therefore, the circuit needs only about 25% of the tuning capacitance required by the conventional circuit of Fig. 1. With $L_1 = L_2 = L$ we have for the circuit of Fig. 1, $C_1 = 2/(\omega^2 L)$. The circuit of Fig. 2 requires $C_2 = 1/(\omega^2 2L)$. Therefore $C_2 = C_1/4$.
2. No dc current flows through the ac ring magnet coils.
3. No ac current flows through the dc coil.

4. The dc circuit couples to the ac circuit. However, the net voltage induced in the ac coils when the dc circuit is first energized is relatively small.

5. The ac circuit is not coupled to the dc circuit.

It has been proposed to introduce higher harmonic components into the magnet current waveform,[3] or to use a sinusoidal magnet current with different frequencies in the half waves for the magnetic guide field[3,4] for the following effects.

- The maximum $\dot{B}$ is reduced during acceleration; hence, the rf power requirements are reduced considerably.
- Lengthening of the guide-field rise time and shortening of the fall time improves the duty factor of acceleration.
- With dual frequency excitation not only the maximum $\dot{B}$ is reduced but also the minimum of the magnet guide field is flattened (front porch for injection).

Figure 3 compares B and $\dot{B}$ values for:

- single frequency excitation (f_o) —··— ,
- ac excitation with the addition of a 2nd harmonic (f_o, $2f_o$) – – – – .
- ac excitation with a 2nd and 3rd harmonic (f_o, $2f_o$, $3f_o$) -------- ,
- two cases for excitation with different frequencies during acceleration and magnet reset ($\frac{2}{3} f_o$ & $2f_o$, $\frac{3}{5} f_o$ & $3f_o$) ——— .

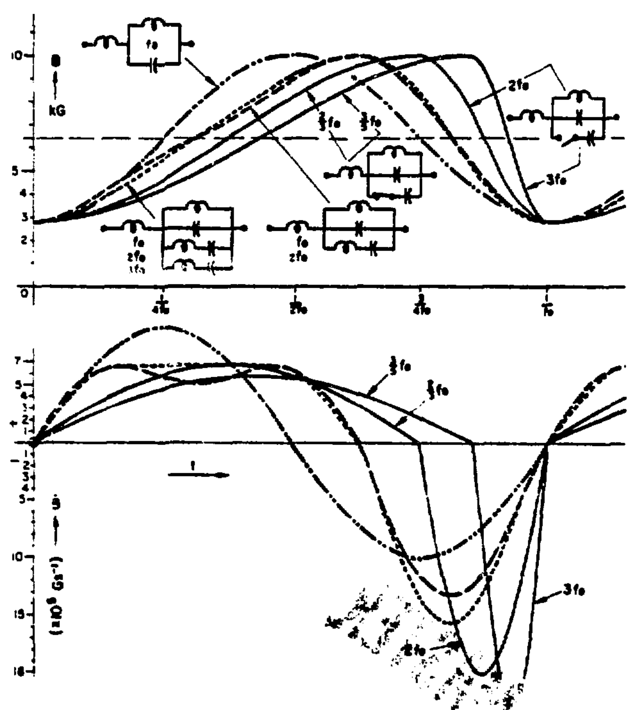

Fig. 3. B and $\dot{B}$ values for various magnet excitations.

Dual Aperture Dipole with 2nd Harmonic

As shown in Fig. 3 adding a second harmonic reduces $\dot{B}$ during acceleration by approximately 33% and makes the rising field approximately 28% longer as compared to single frequency excitation. The addition of a 3rd harmonic gives not much further improvement and complicates the circuit considerably.[3]

A second harmonic may be added to the circuit of Fig. 2 if we use laminated iron throughout and add a second harmonic coil that totally surrounds the first harmonic coils. Figure 4 illustrates such an

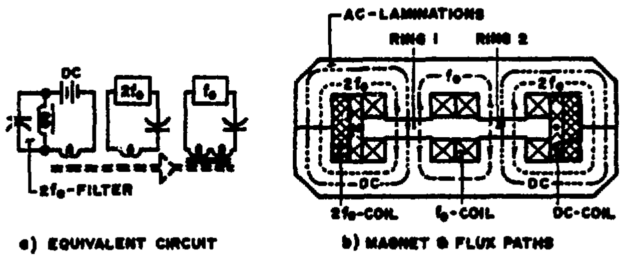

Fig. 4. Two rings with common windings, core, and power supplies.

arrangement. For sake of simplicity two identical rings are shown. The rings could have different gaps, one being a booster synchrotron injecting into the other.[1] Figure 5 shows the flux phase-relation. Since the second harmonic is coupled to the dc circuit a second harmonic parallel-tuned circuit is added to the dc circuit to reduce the induced second harmonic current. Again, the first harmonic circuit does not couple to the dc or to the second harmonic circuit. This fact is illustrated in the equivalent circuit by an arrow in the dotted lines which represent the magnet iron. The arrow illustrates the direction of flux coupling.

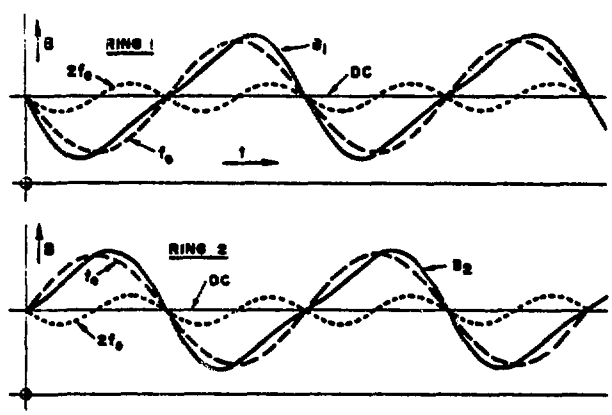

Fig. 5. Fluxes in two-ring core with first (f_o) and second harmonic ($2f_o$) excitation.

The dc coil may use radiation-hardened metal-jacketed mineral-insulated conductors soldered into a monolith to protect the ac coil from radiation. Of course the dc coil could also be superconducting to save power.

The above system is especially suitable for a synchrotron having combined function magnets. Such magnets would greatly reduce the total number of magnets, magnet supports, power supplies, interconnections, vacuum chamber transitions, etc. as compared to a synchrotron with separated function ring magnets. There also would be savings in first-cost and in power consumption.

References

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