RF SYSTEM CONSIDERATIONS IN INTERLACED-BEAM INJECTOR SYNCHROTRONS*

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Summary

The general characteristics of the RF system high-power components and suitable accelerating structures have been studied for several variations of the interlaced multi-ring synchrotron. This type of machine has been considered as a possible component of the injection system for the 200-BeV accelerator.

Introduction

Many different types of injectors have been proposed and considered for the 200-BeV accelerator.[1] One type which has been subjected to extensive engineering analysis is the interlaced-beam synchrotron having several independent orbits which share some of the accelerator components such as gradient magnets and accelerating cavities.

Several applications of this general machine type have been considered. Among these are an 8-BeV four-ring QUART replacing the conventional rapid-cycling booster, and a three-stage injection scheme incorporating a 400-600 MeV QUART or three-ring TART between a 30-60 MeV linac and the 8-BeV rapid-cycling booster. Of the many possible schemes, the three-stage scheme appeared to be the most attractive and hence received the most detailed analysis.

General Machine Parameters

Two variations of a weak-focusing interlaced multi-beam synchrotron were studied in detail. The general parameters pertinent to RF system design of these two machines (TART and QUART) are listed in Table I. As one would anticipate from the similar sets of parameters for these two machines, the electrical characteristics of the RF acceleration systems for these two machines are very similar. The combination of a larger number of magnets, smaller machine radius, and greater number of beam crossings in the QUART resulted in a very tight mechanical layout of the accelerator components. Accelerating cavities with drift tubes shorter than a half-wavelength were required if one wished to match RF frequencies of the QUART and the 8-BeV booster. The set of parameters chosen for the TART allowed a greater amount of clearance between components and provided ample drift length between magnets for RF cavities having half-wavelength drift tubes.

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Table I. Machine parameters.

	TART	QUART
Number of beams	3	4
Machine radius (m)	28.8	21.6
Ejection energy (MeV)	600	600
Peak magnetic field (kG)	10	12
Injection energy (MeV)	28	28
Magnetic radius (m)	4.1	3.4
Number of bending magnets	24	32
Repetition frequency (Hz)	21	21
Guide field	sinusoidal	sinusoidal
Intensity (p/pulse)	3.8×10^{12}	3.8×10^{12}

TART RF System

A plot of peak RF voltage as a function of time required to contain the momentum spread and provide acceleration with some safety factor is shown in Fig. 1, and a plot of the required radio frequency as a function of time is shown in Fig. 2. The large tuning range of approximately 2.5 to 1 is one of the dominating factors in choosing an RF system for this machine. An accelerating structure which can operate over a wide frequency range is required.

Although the three interlaced beams share the same magnet structure, it is feasible and perhaps desirable to give each beam its own independent accelerating components. It is not clear, however, that individual control of the beams is essential for the accelerator to operate successfully. Although the three beams have separate orbits, these orbits intersect each other periodically around the ring. These intersections are forced to be at small angles by constraints such as ring diameter, magnet size, and peak field allowed. The small angle of intersection and nonzero widths of each of the beams result in very short and narrow regions in which to place individual beam-accelerating structures. This situation, coupled with a desire to match the ejection radio frequency of the TART to the injection frequency of the 8-BeV booster, leads one to consider accelerating structures which span the full width of the interlaced beams and provide acceleration for all the beams simultaneously. If individual control of the separate beams is necessary, small, inexpensive trimming cavities can be used to provide individual orbit control.

A ferrite-tuned resonant cavity with a half-wavelength drift tube to span all three beams is shown schematically in Fig. 3. This cavity is an adaptation of the cavity design proposed for the 8-BeV rapid-cycling booster which has been previously described.[2,3] The end of the cavity which is shown open in the figure would be closed off (except for beam clearance holes) with connections to the accelerator vacuum system. The ferrite required for tuning is placed in four separate stacks or tuners, all connected in parallel to maintain a low impedance in this section of the cavity where the RF currents are highest. A separate RF power amplifier for each cavity would be mounted as an integral part of the accelerating structure, since the output circuit of the amplifier forms part of the resonant circuit which must be tuned over the 2.5 to 1 frequency range. All other electronic components, including ferrite biasing supplies, would be located remote from the cavity to provide radiation protection and access for maintenance during operation. The cavity dimensions for the TART with parameters as in Table I are given below:

a	92 cm
b	11.6 cm
ℓ	2.82 m
h	40.8 cm
D1	34 cm
D2	50 cm

The requirements of an RF system based on this cavity design and individual modules compatible with those proposed for the 8-BeV booster and 200-BeV main ring were determined and are given in Table II, along with rough cost estimates for the system. The cost figures are for hardware only and do not include any safety factors, development costs, or contingencies.

Figure 4 shows the RF power that must be supplied to the cavity by each RF amplifier in the system as a function of time. It is obvious that the ferrite losses dominate the system, as one might expect from the wide tuning range required. One way to reduce the size and cost of the RF system is to reduce the energy range of the accelerator. The tuning range is more sensitive to a change in the injection energy than to an equal change in the ejection energy. An indication of the effect of linac energy on the size and cost of the TART RF system is given below:

Linac energy (MeV)	Freq. range (MHz)	Cavities	Cost (k$)
28	12.7-42.1	9	3 250
50	16.7-42.1	7	2 420
60	18.1-42.1	6	2 210

As the figures indicate, the size and cost of the RF system are reduced if one chooses a higher linac energy. However, the higher energy linac is more expensive, so any attempt at optimization must consider the overall accelerator.[4]

Table II. Parameters and cost of TART RF system.

System Parameters	
Number of cavities installed	11
Number of cavities operating	9
Total system RF power, maximum (kW)	370
Total ferrite volume (m^3)	1.3
Injection frequency (MHz)	12.7
Ejection frequency (MHz)	42.1
Harmonic number	32
Ferrite $\mu\Delta$ range	33.5-1.5
Peak gap voltage, maximum (kV)	8.8
Cost of Components	**k$**
Final power amplifiers	360
Driver and predriver amplifiers	250
Power supplies, modulators, controls	1 070
Accelerating cavities and ferrite system	1 460
Miscellaneous	110
System total	3 250

References

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3. 200 BeV Accelerator Design Study, Lawrence Radiation Laboratory Report UCRL-16000, June 1965.

4. F. B. Selph and J. M. Peterson, Selection of Injector Synchrotron Parameters to Minimize Cost of the 200 BeV Accelerator, paper G-18, this conference.

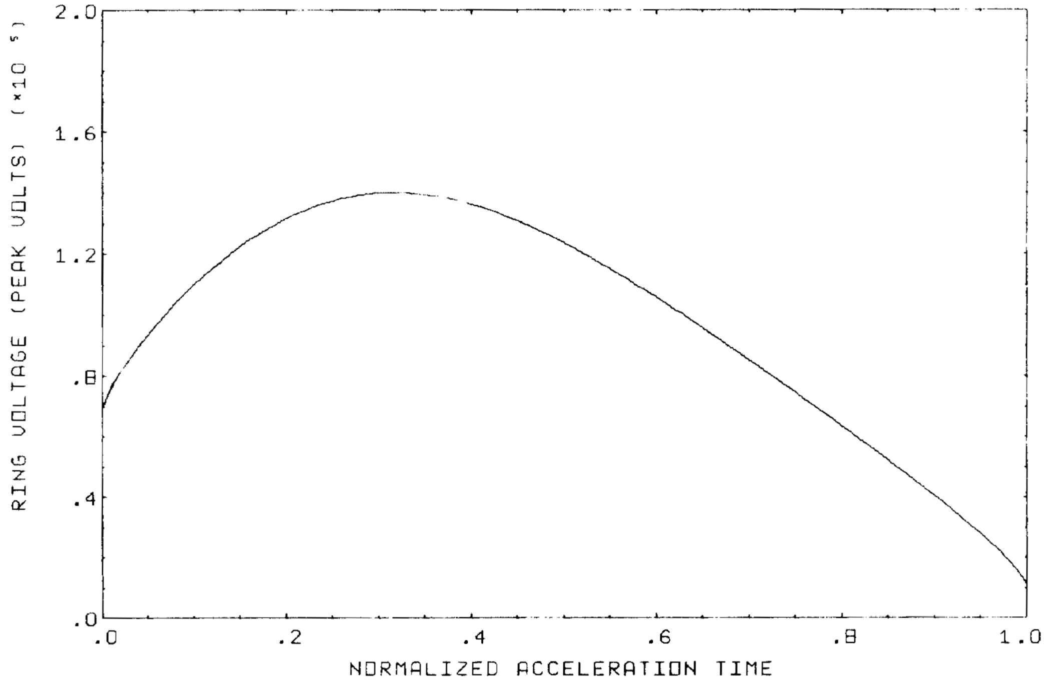

Fig. 1. Peak RF voltage vs time for 24-magnet weak-focusing 600-MeV TART RF system.

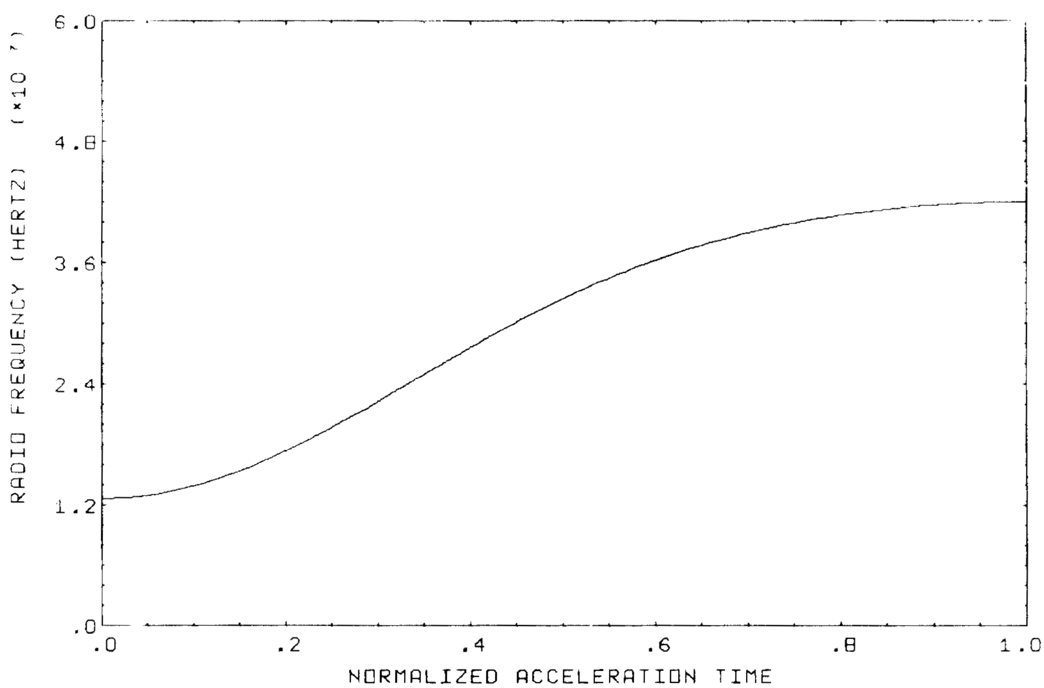

Fig. 2. Radio frequency vs time for 24-magnet weak-focusing 600-MeV TART RF system.

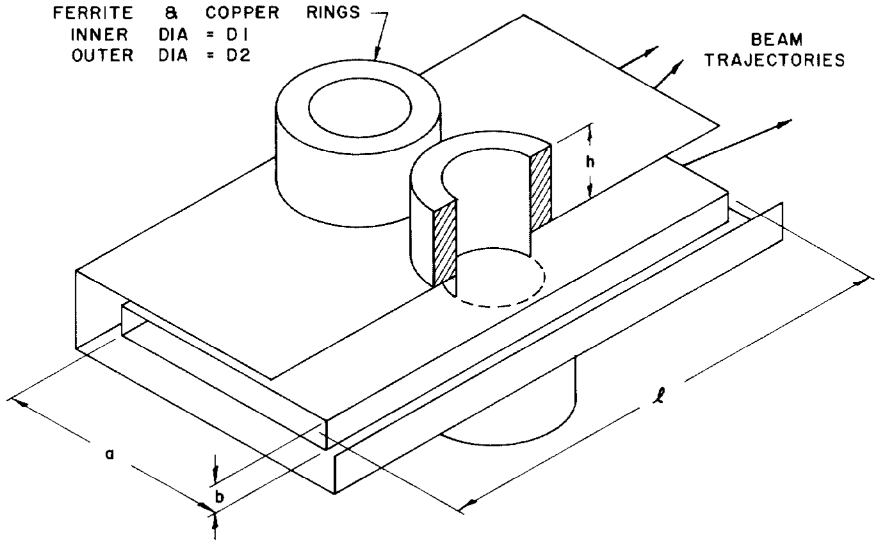

Fig. 3. Typical accelerating structure—idealized.

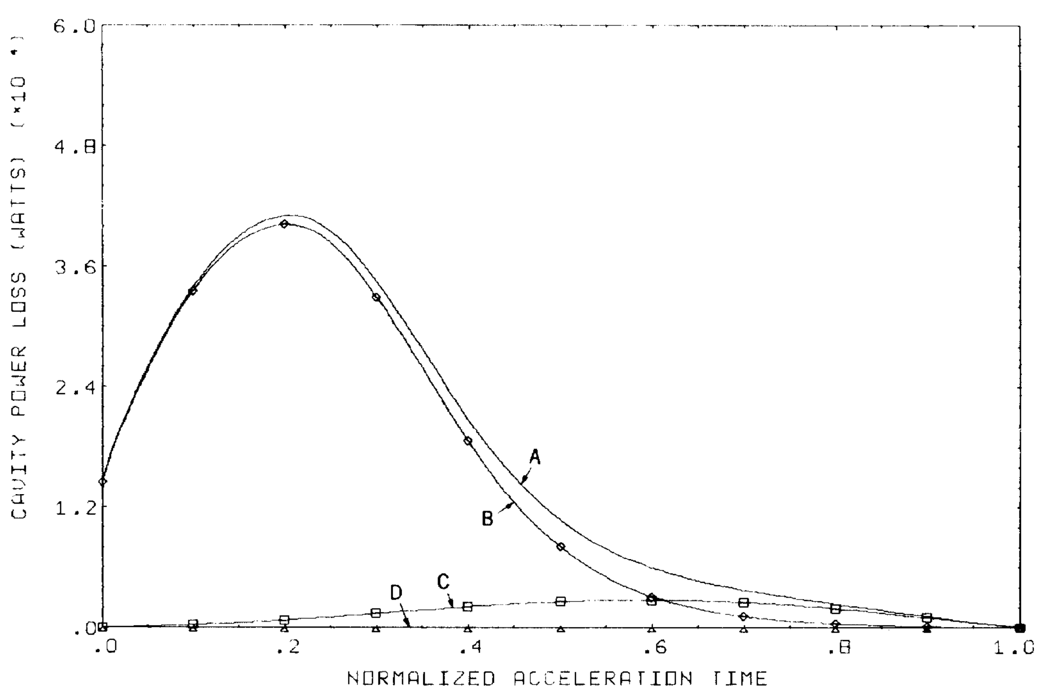

Fig. 4. Individual cavity RF power vs time. A, total power; B, power dissipated in the ferrite; C, power delivered to the beam; D, power dissipated in the copper parts of the cavity.