Rapid Cycling Synchrotrons

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120 Hz 8 GeV Fermilab Proton Booster Notes

- 15 Hz, 0.5 MW $\longrightarrow$ 120 Hz, 4 MW synchrotron proton driver
- ISIS synchrotron: 50 Hz. Large power generators: 60 Hz.
- Magnet Formulas : $I = B\,h/\mu_0 N, \quad V = 2\pi\,B\,f\,N\,w\,\ell$
- Lower Eddy Current Loss Options
  Power Lost = [Volume]$(2\pi\,f\,B\,t)^2/(24\rho)$ t = thickness.
  Move magnet coils into lower B fields. Use thinner copper.
  Stainless steel water cooling tube made by Trench Ltd.
  New ISIS chokes use SS tubes surrounded by copper wire.
  Thinner, higher resistance silicon steel: 3% grain oriented.
- FNAL Booster: 4×10^{12} protons/pulse
  FNAL Synchrotron Proton Driver: 2.5×10^{13} protons/pulse
  JHF 3 GeV Synchrotron: 8.3×10^{13} protons/pulse
- Ameliorating Beam Losses
  Larger bore magnets and RF cavities
  Higher injection energy. Space charge falls as $\beta\,\gamma^2$
  Lower beta lattice. 6σ beam size = 6 $\sqrt{\epsilon_t\,\mathrm{beta}/(6\pi\,\beta\,\gamma)}$

Magnet Steel Lamination Properties

Material	Composition (%)	ρ ($\mu\Omega$-cm)	H_c (Oersteds)
Low Carbon Steel	Fe, C .0025	10	1.0
3% Silicon Steel	Fe 97, Si 3	47	0.7
Grain Oriented Steel	Fe 97, Si 3	47	0.1
JFE Super Core	Fe 93.5, Si 6.5	82	0.2
Metglas 2605A1	Fe 81, B 14, Si 3, C 2	135	.03

- Eddy Current Loss = [Volume]$(2\pi\, f\, B\, t)^2/(24\rho)$
  High ρ is good. t = lamination thickness.
- Hysteresis Loss = $\int H\, dB$. Low coercivity (H_c) is good.
- Vendor: TC Metal Company Slitting and Shearing
  \$3/lb for slit and sheared .23mm grain oriented silicon steel
- Magnet Measurement: F. W. Bell Model 4048 Hall Probe.
  Measure to 2T with an accuracy of 2% from 100 to 3000Hz.

Preliminary 120 Hz 8 GeV Fermilab Proton Booster

	15 Hz Booster	120 Hz Booster
Ring Circumference	472 m	472 m
Rise Frequency	15 Hz	80 Hz
Fall Frequency	15 Hz	240 Hz
12% Magnet Power 2 f Harmonic	No	Yes
No. of RF Cavities	17	68
RF Ring Fraction	8%	32%
Magnet Ring Fraction (0.7 T)	60%	60%
Magnet Lamination Thickness	0.64 mm	0.23 mm
Magnet Lamination Silicon Steel	3% non-oriented	3% oriented
Loss @ 60Hz, 1.5T	2.1 w/lb	0.39 w/lb
Copper Wire Size	12×12 mm	1.5×1.5 mm
Magnet 'Good Field' Bore	50×110 mm	100×150 mm
Magnets/Power Supply	2	1
Turns/Magnet	48 or 56	48 or 56
Maximum AC Voltage	450 Volts	5000 Volts
Maximum Current	1000 Amps	2000 Amps
Injection Energy	400 MeV	600 MeV
8 GeV Protons/cycle	4×10^{12}	2.5×10^{13}
8 GeV Beam Power	0.04 MW @ 7.5 Hz	4 MW

To Do List

- **Can ferrite loaded RF cavities handle 12x more beam power?**
  Radial biased yttrium garnet with liquid dielectric cooling.
  M. Popovic et al., Compact, Tunable RF Cavities, EPAC08.
- **Calculate magnet and RF wall power.**
  Existing Magnets: 1.3 MWatt
  Existing RF (Axial biased Ni-Zn ferrite): 1.7 MWatt
  Higher RF efficiency needed.
  4x more cavities. 12x more beam power each.
- **Estimate magnet power supply parts cost (96 magnets).**
  Capacitors: \$5/joule.
  Charging Power Supply: \$1.20/watt + \$3000.
  Controls: \$2500.
  Enclosure: \$5/joule
  Choke: \$3/joule.