Induction Linac Technology for Muon Beam Phase Rotation

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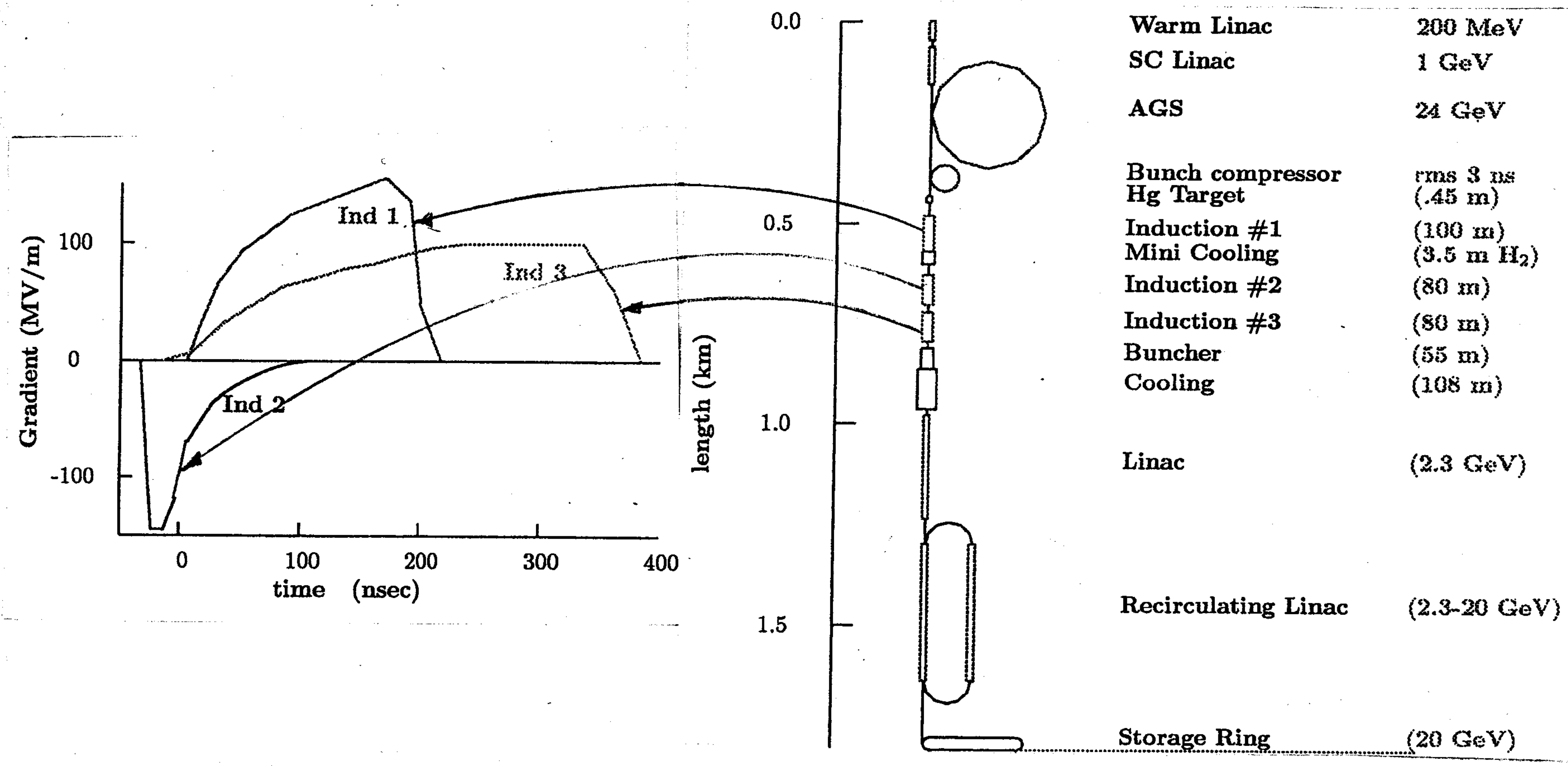
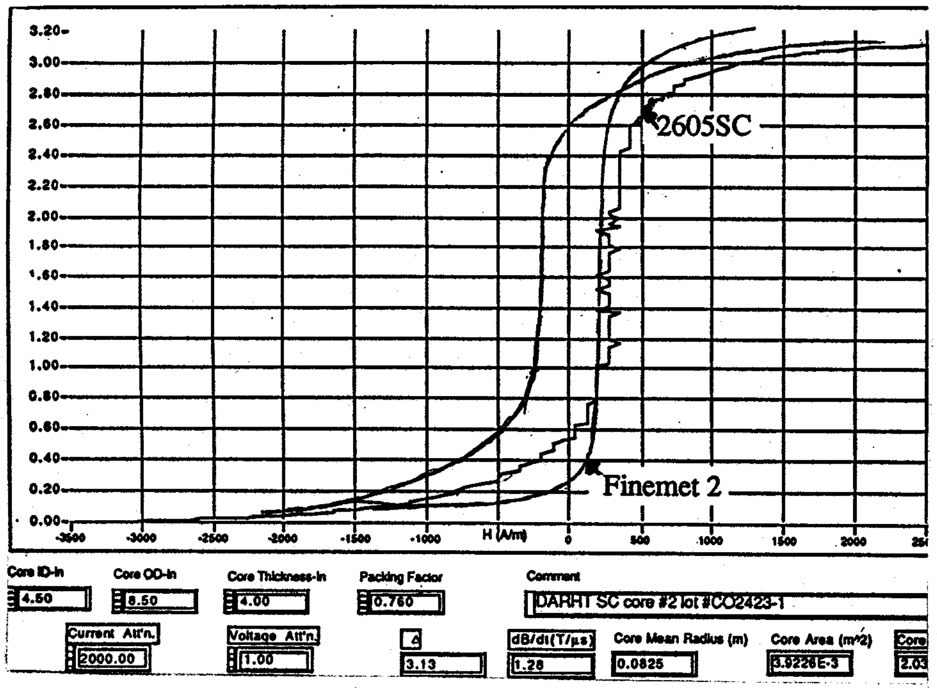
Induction Accelerators

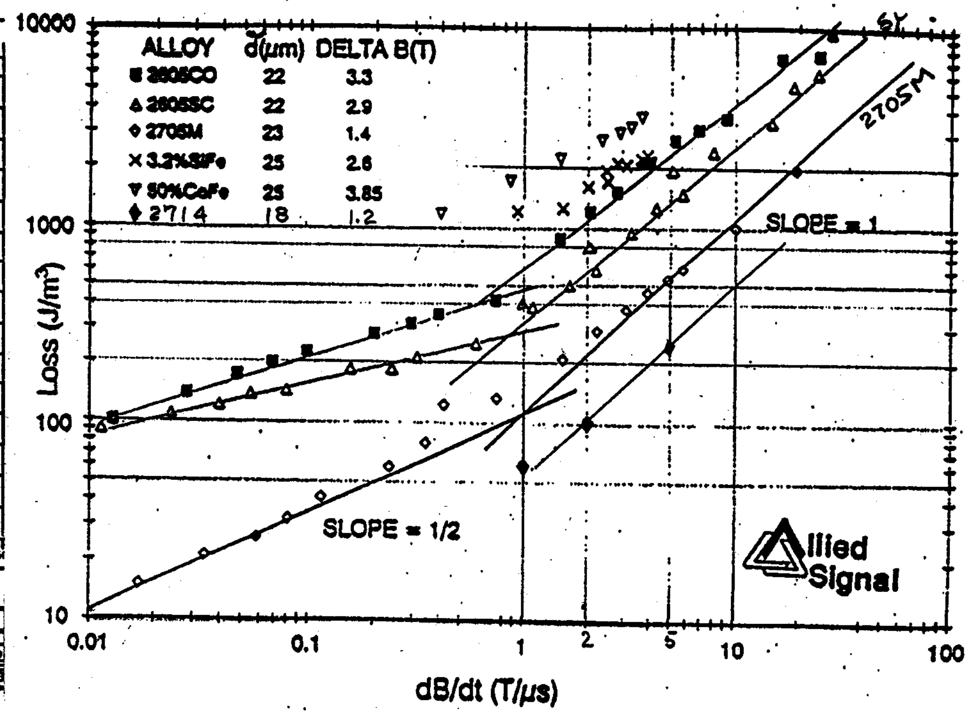


Induction Cell Design

- The magnetic material is chosen for minimum cost including the cost of the pulse power but fully satisfying the requirements.
- Minimum cost of the amorphous alloy is achieved by casting the material wider than 10.16cm. Cell design should accomodate this width.
- Since the magnetic losses are inversely proportional to the ribbon thickness squared, an effort should be made to manufacture the material thinner than the present 20um.
- The crossover in choosing between ferrites and amorphous material in terms of minimizing the losses and the cost for different pulse durations, seems to be at about 100ns. Induction1&3 will use Amorphous materials and Induction2 will Use Nickel-Zinc Ferrites.

Magnetic Materials

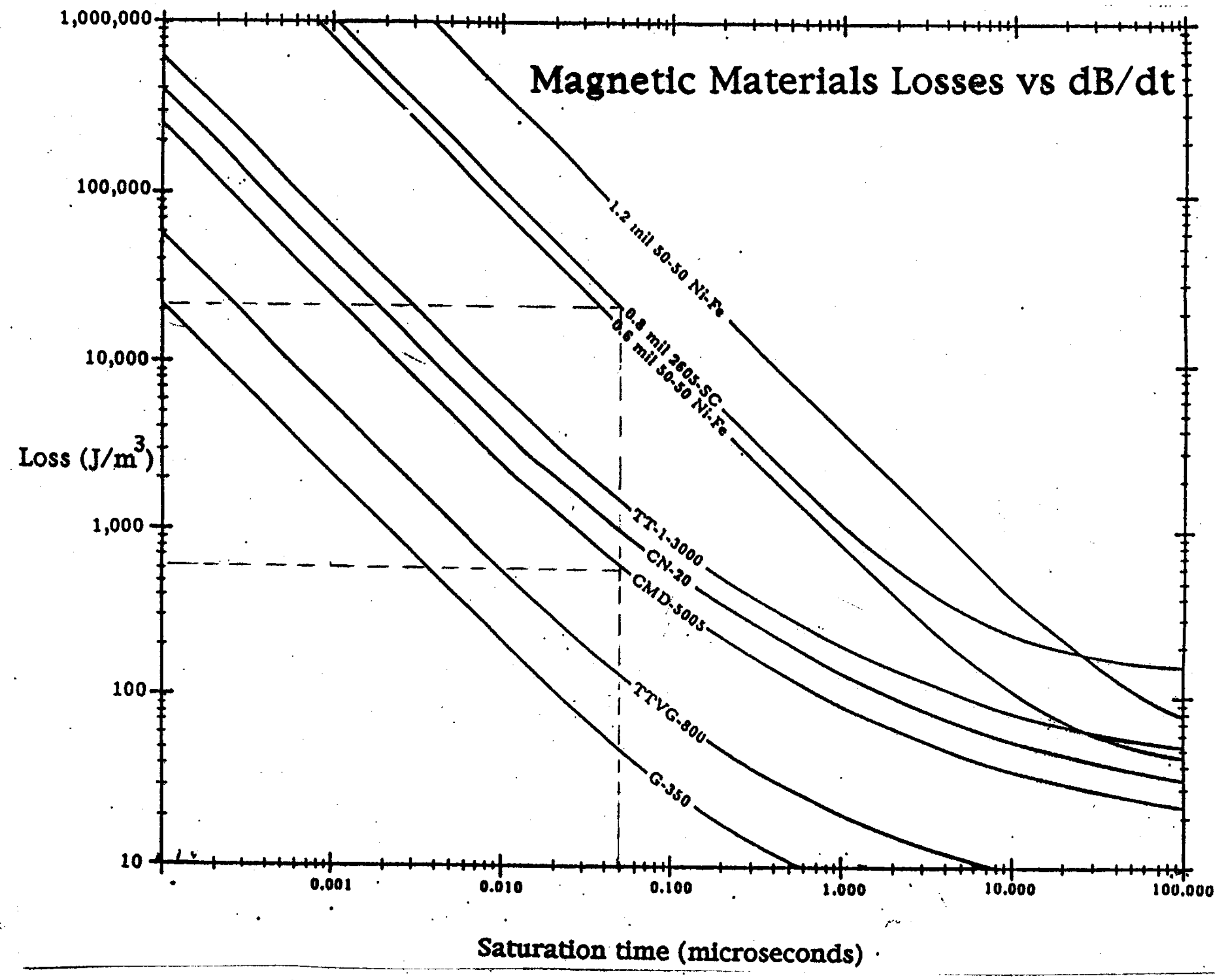




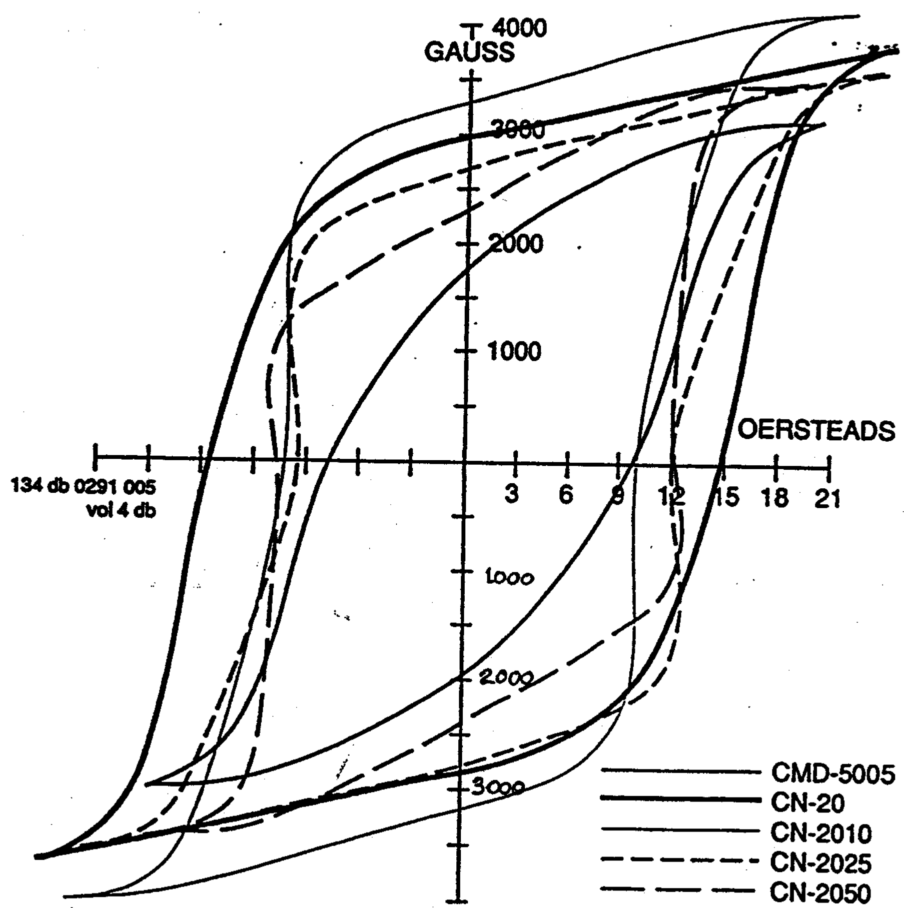
- In low current(1000A) induction accelerators, the magnetic properties are critical to the design.

- Nearly all the energy is delivered to the core as magnetization energy and it is directly proportional to the magnetization rate or dB/dt.

Magnetic Material Losses

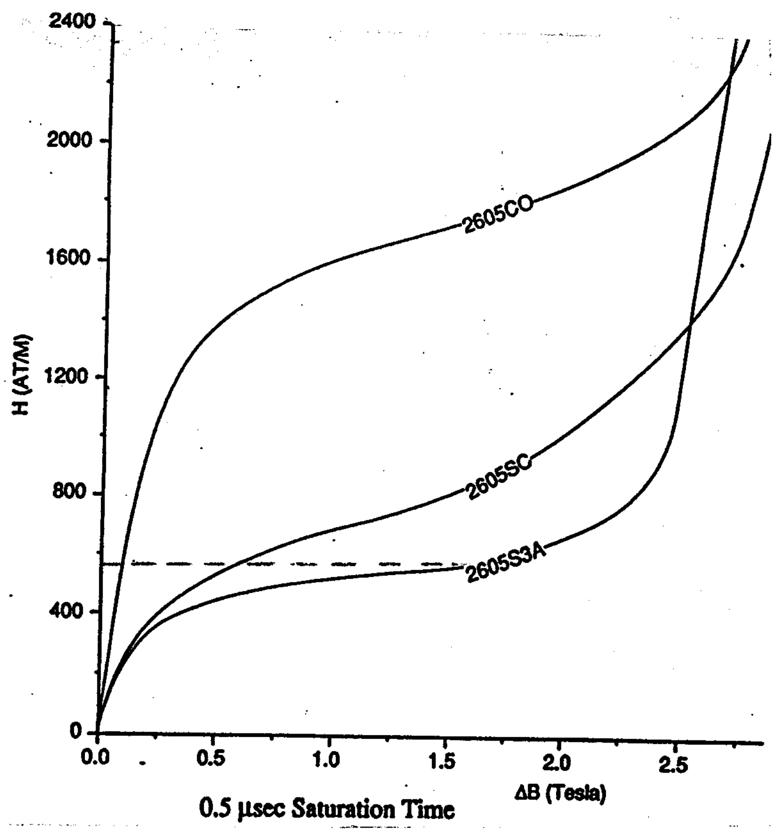


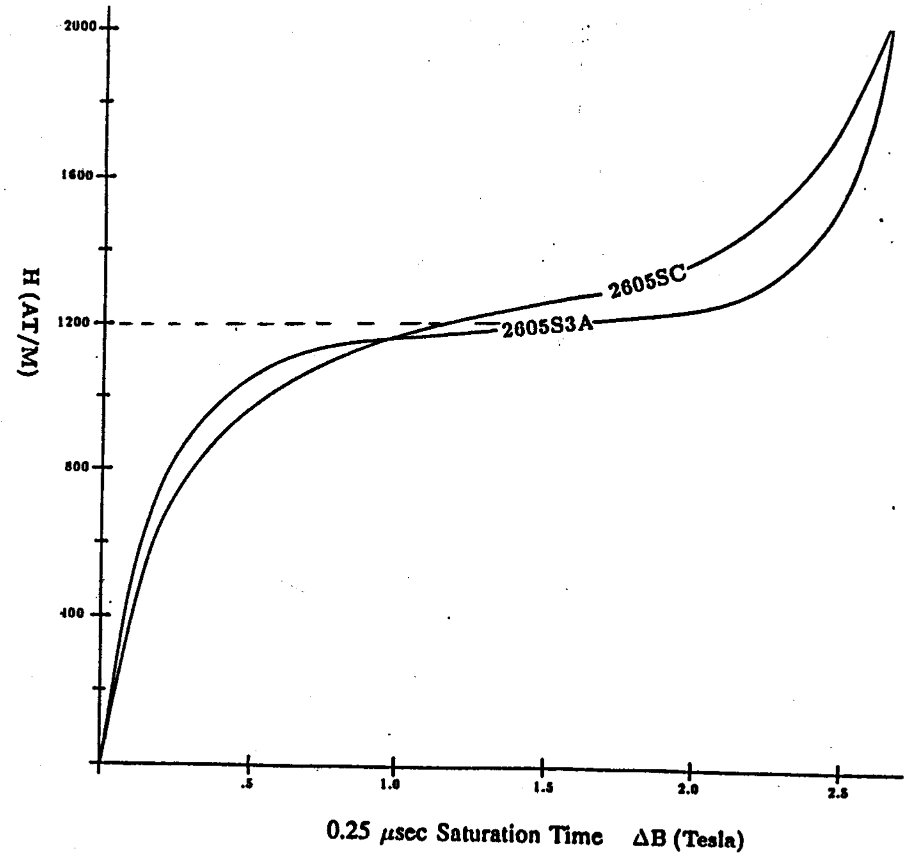
Ferrites B-H Loop @ 50ns Saturation



Hysteresis curves measured at $\tau_{sat} = 50$ ns

Amorphous Alloys @ .25us and .5us Sat.





Magnetic Materials

- When choosing a magnetic material for different pulse durations Induction accelerators, it is essential to understand the attributes of ferrites ,amorphous and nickel-iron materials.

- The magnetization rate,the resistivity,ribbon thickness, permeability and flux swing, impact the losses and the BH loop linearity.

Basic Design for Induction Accel.

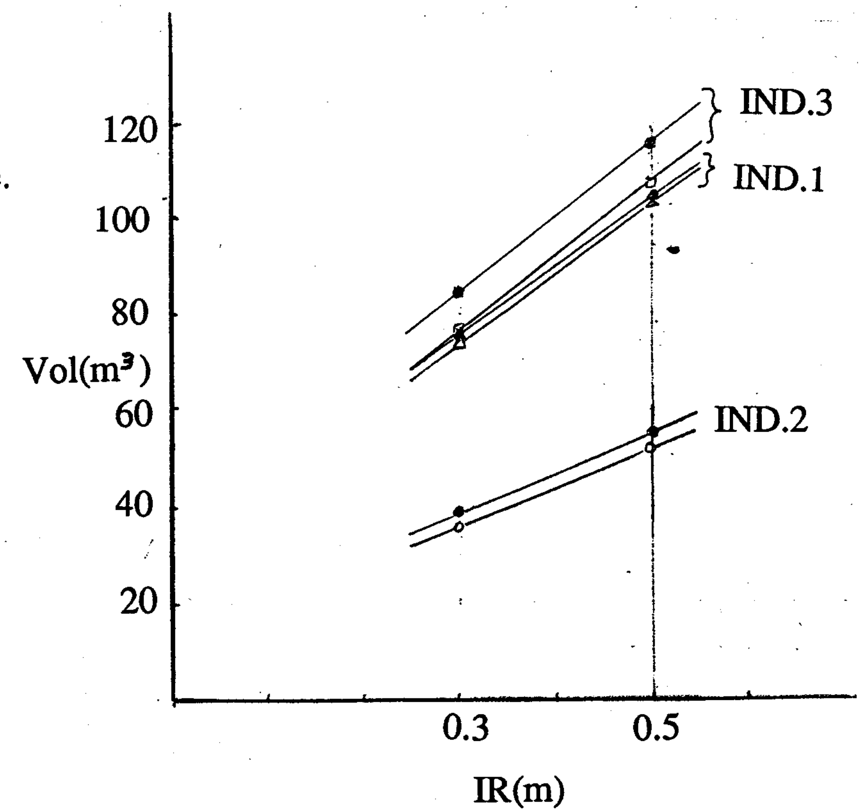
	MV/m	Δt FWHM ns	L m	IR m	OR m	Volu. eq/tot m³	Wgt[1] eq/tot Kg	ΔB Tes	ΔH kA/m	V kV	I kA	U kJoule Tea/Tt	Mat	W m	PFZ/PFR
INDUCTION 1	1.50	250	100	.5	.85	.151 105.6	826 578T	2.0	1.20	214	5.09 35.6	1905 190.5	Amor.	.1016	.71/.75
	1.25	250	120	.5	.80 (.794)	.125 104.6	683 571T	2.0	1.20	179	4.9 34.3	1535 184			
INDUCTION 2	1.50	50	80	.5	.75 (.685)	.0996 55.86	374 209.T	0.5	1.20	188	4.7 33.0	310 24.8	Ni-Zn	.1016	.71/1.0
	1.20	50	100	.5	.70 (.648)	.0766 53.6	287 291T	0.5	1.2	150	4.5 31.7	.238 23.8			
INDUCTION 3	1.00	360	80	.5	.95 (.942)	.208 116.6	1137 637T	2.0	0.8	179	3.64 25.5	1.64 131.5	Amor.	.1016	.71/.75
	.80	360	100	.5	.85 (.838)	.151 105.6	826 578T	2.0	0.8	143	3.39 23.8	1.23 123			

[1] 7290 Kg/m³ for Amorphous Materials and 5000 Kg/m³ for Ni-Zn Ferrite
Packing factor for Amorphous Material – 0.75

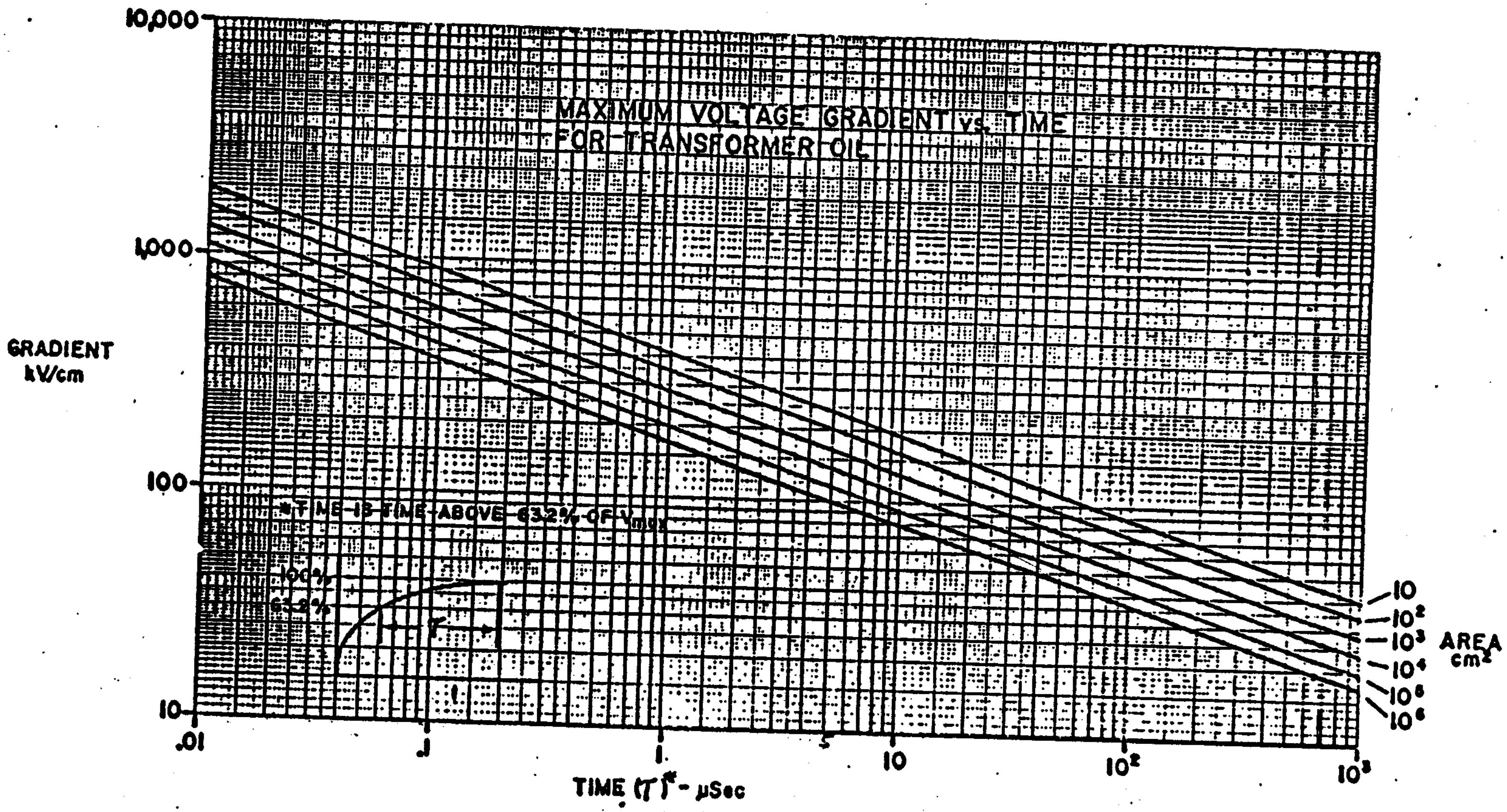
Core Volume vs Gradient and Radius

- Reducing the gradient has less of an impact but has the advantage of reducing the drive voltage so that standard components are readily available.

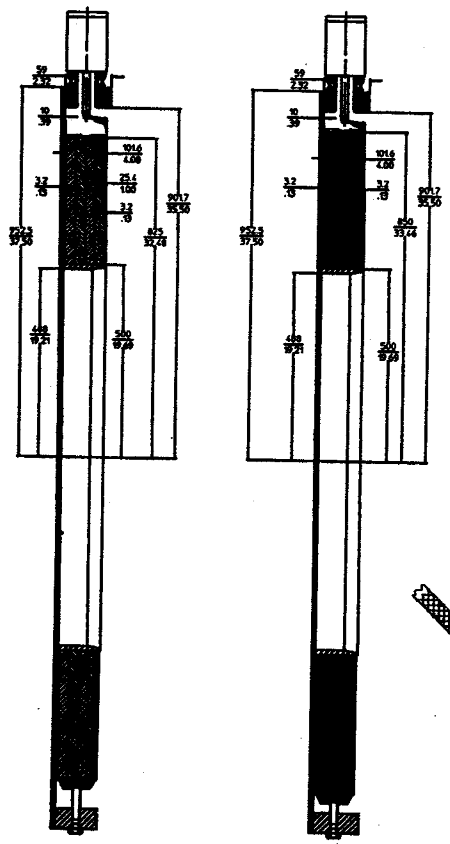
- Reducing the IR of beam pipe has the greatest Impact on volume reduction, hence the cost of magnetic materials and drive power.



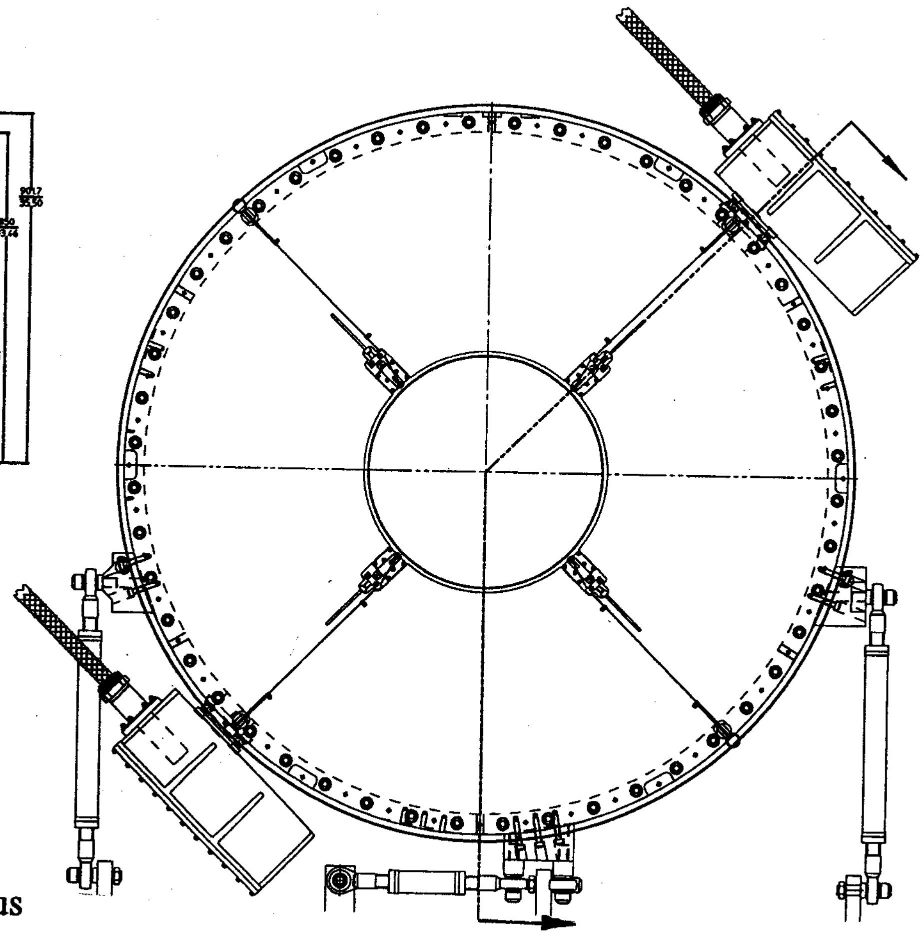
Pulse Breakdown in Oil



Cell Design for Induction 1,2,3

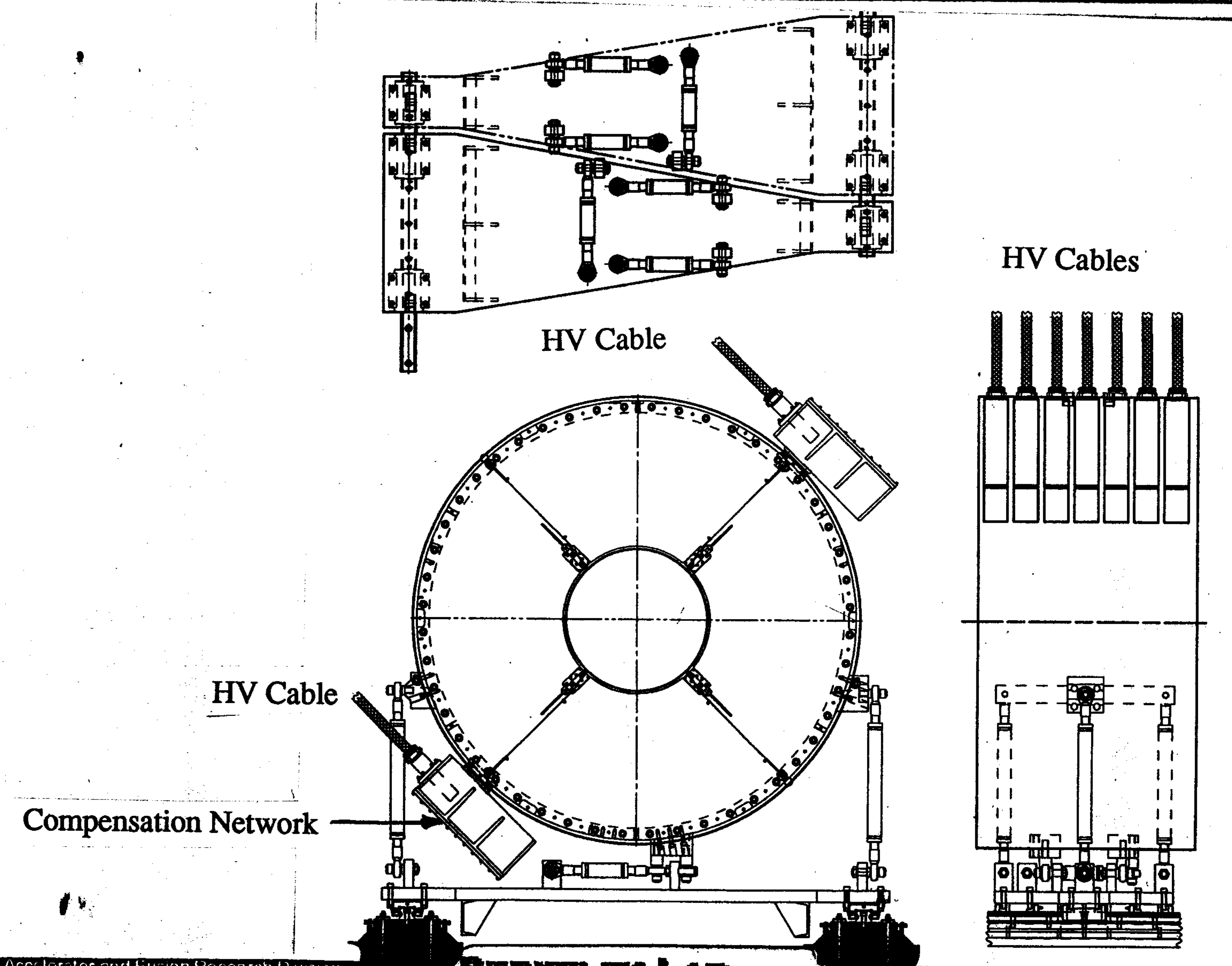


Ferrite Amorphous

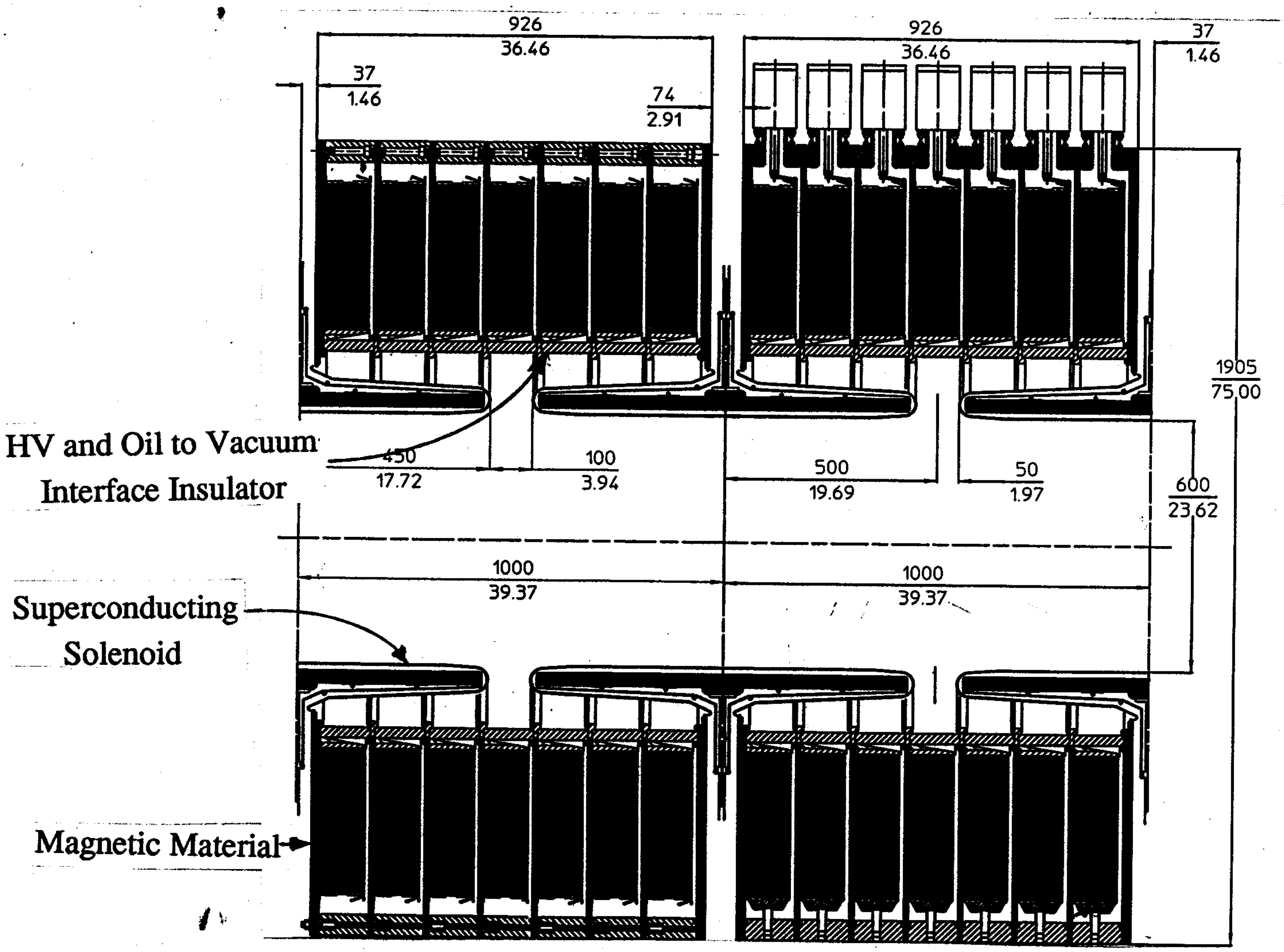


- The cell(core) inside radius will be reduced untill the solenoid leakage flux begins to affect the magnetic materil deltaB.

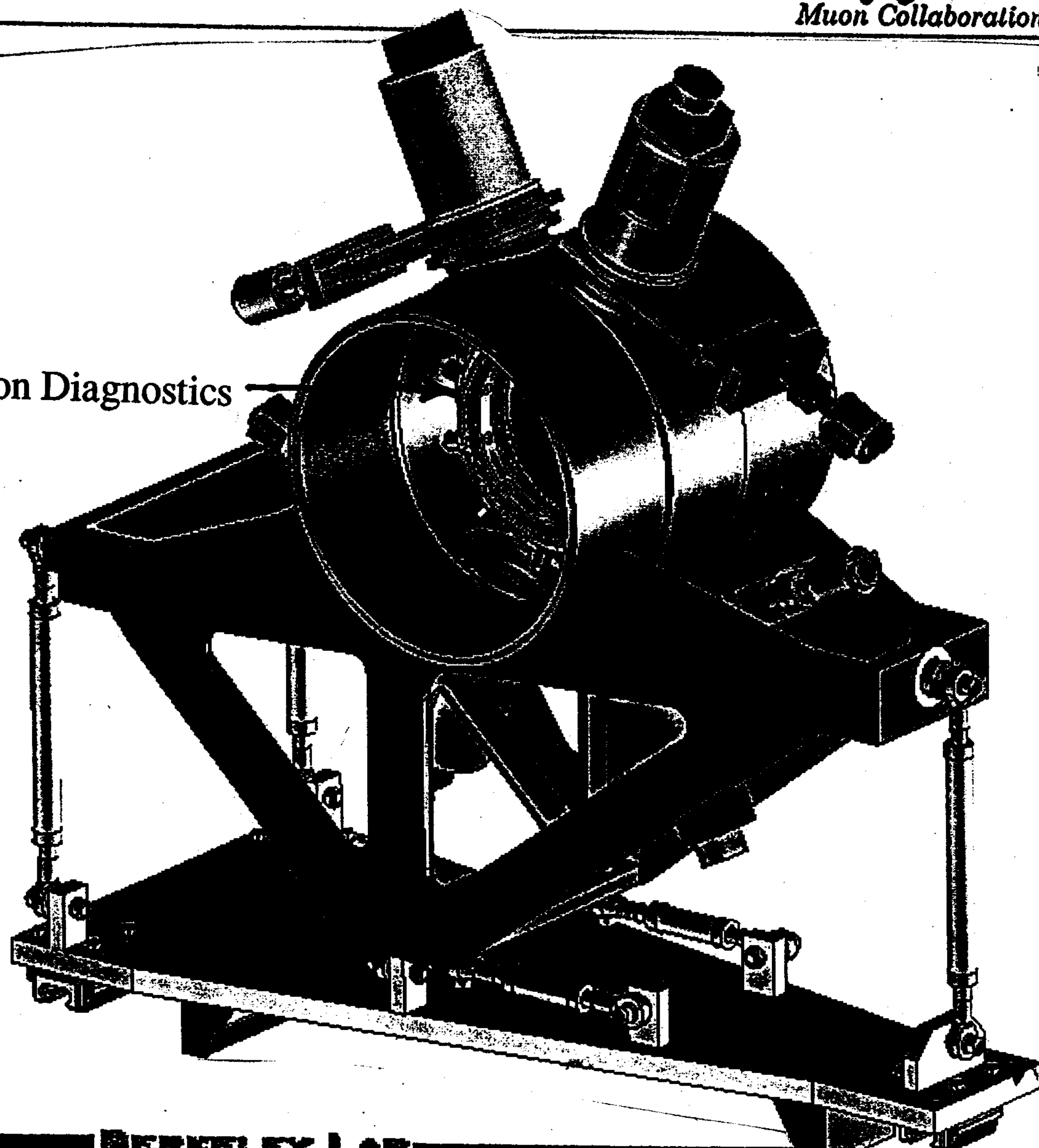
Six Strut Cell Support



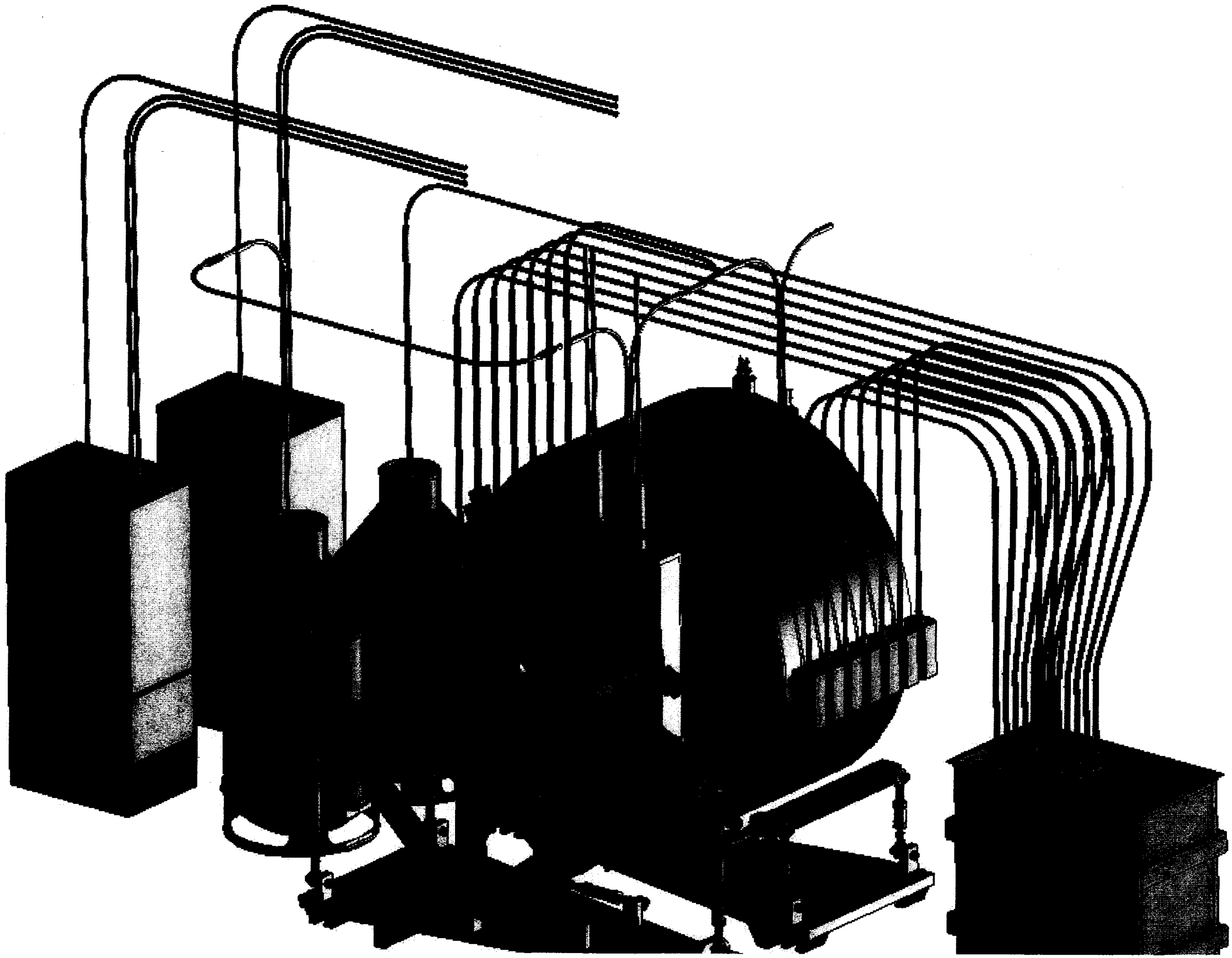
Two Cell-Modules Assembly



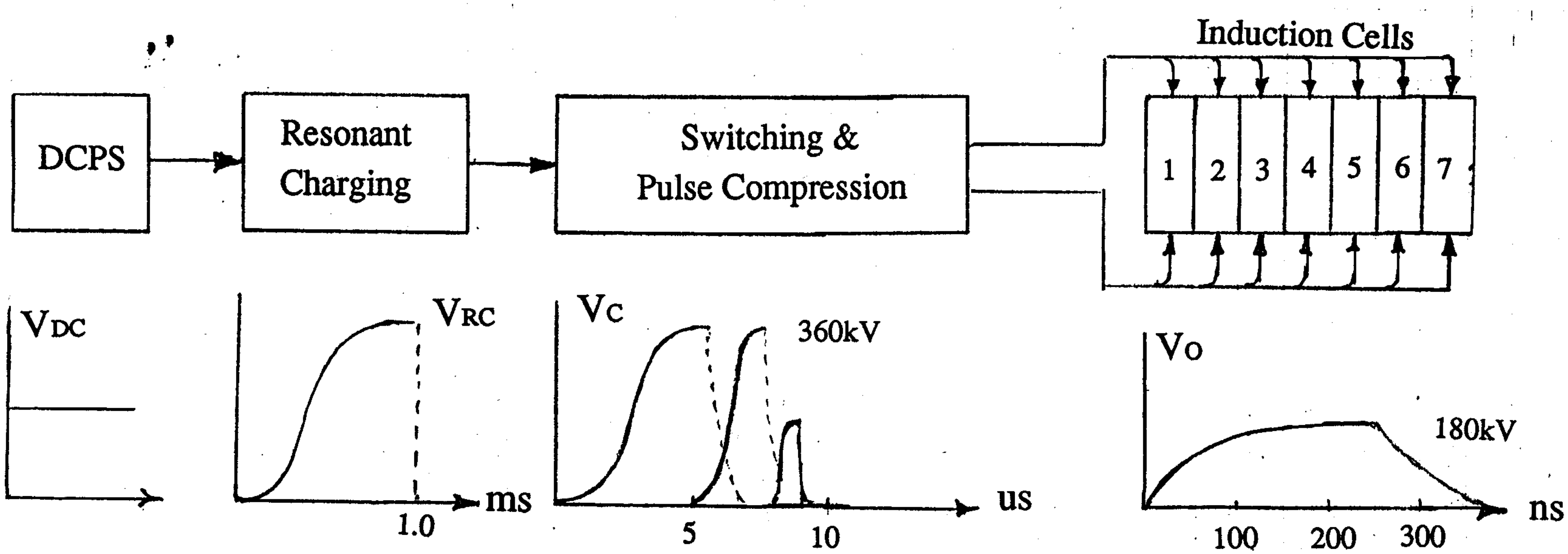
Intercell

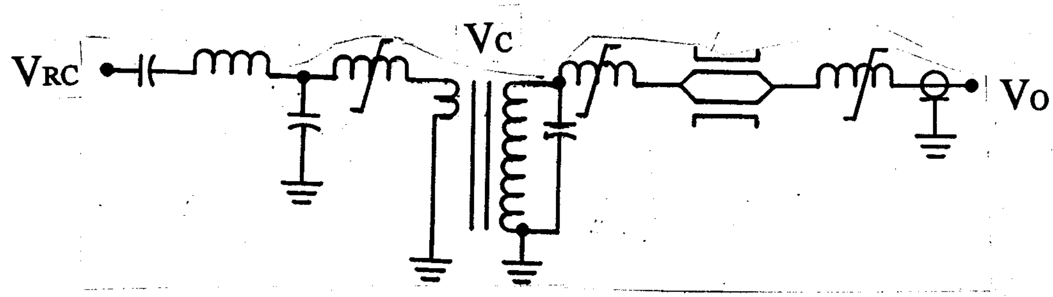


Total Current and Beam Position Diagnostics



Induction Cells Drive System





Preliminary Cost Estimates

Magnetic Material	IND.1	IND.2	IND.3	Total
		(see mechanical costs for the cells)		
DCPS and Resonant Charging(@8$/W)	18.3	2.38	12.64	33.32M$
Magnetic Pulse Compression(@150-200$/J)	28.6	4.96	19.7	53.26M$
Reset Pulsers for Cores and Pusers(@20$/J)	3.82	4.96	2.62	11.40M$
	50.72	12.3	34.96	97.98M$
	42.6	9.84	27.97	80.41M$

Electrical and Mechanical Cost

Muon Collaboration

	INDUCTION 1		INDUCTION 2		INDUCTION 3	
	100 meters	120 meters	80 meters	100 meters	80 meters	100 meters
Cryogenic Magnet System	$21.90	$21.90	$21.90	$21.90	$21.90	$21.90
Accelerator Cells	$42.15	$50.32	$33.92	$42.07	$34.24	$42.15
Pulse Power System	$50.72	$42.6	$12.3	$9.84	$34.96	$27.97
Total	$114.77	$114.82	$68.12	$73.81	$91.10	$92.02
			12.3	9.84		
Grand Total						
Baseline	274.0M$					
Lower Gradient	280.7M$					

- If no cells but pulsers combined with IND 3

Near Term Studies

Investigate Thinner Amorphous Materials

Review Application of Amorphous Materials in Place of Ferrites

Perform Simulation Studies of Solenoid Leakage Fields

Perform Actual Tests of Field Effects on Ferrites and Amorphous Materials

Optimize Pulse Compression Scheme

Review Reset System for Induction Cells and Magnetic Pulse Compression

Ferrite vs Amorphous Magnetic Materials

- Initially thought that amorphous magnetic materials losses would be excessive and not achievable (ie 20,000 J/m^3).
- Since the volt-seconds for the negative pulse of IND2 are much lower than for IND 3 then the magnetization rates will be also much lower.
- Amorphous materials can be used instead of the Nickel-Zink ferrites that were initially chosen.
- Induction 1 and 2 pulsers can be combined at the cell with independent pulse shape and timing eliminating one ind. accelerator.

Back to Bipolar Pulse with Indep. Pos. & Neg.

- Combine the functions of IND.2 & IND3
- Maintain unipolar pulsers (separate) but combine waveforms at the induction cell.
- Design pulser for IND2 to absorb energy from IND3 pulsers.
- Design IND3 pulser to supply additiona energy to load (ind. cells) and IND2 pulse