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A PARTIAL SNAKE FOR THE AGS*

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Based on snake experiments at the Indiana University Cyclotron Facility and computer simulations at Brookhaven National Laboratory, as well as the conclusions of a BNL mini-workshop, we feel that a partial Siberian snake is a practical device for the AGS. It is anticipated that such a device could reduce the polarized beam tune-up time from 2-3 weeks to 2-3 days.

Requirements:

1. Fit into a 10′ straight section with 6" i.d.
2. Have sufficient strength to correct all imperfection resonances up to $G\gamma = 48$ (above RHIC transition and a "magic" energy which preserves beam polarization in the AGS to RHIC transfer line).
3. Turn on before or at $G\gamma = 6\text{-}1/2$ and off at $G\gamma = 47\text{-}1/2$ on $\nu_s = 1/2$ flattops or ramp between flattops. Nominally take less than 10% of duty cycle (300 msec) for manipulations. Not an absolute requirement. Other scenarios are possible depending on how much duty cycle one is willing to give up.

Solution:

1. Use an air-core solenoid. No orbit distortions and easily rampable in short times. Yields good duty cycle and low power consumption.
2. Choose $L_{eff} = 90"$ (leave about 10" on each side for fittings and another 5" for flanges).
3. $$\int_{\theta_p=\pi} B d\ell = 3.752\ (P_{GeV/c}) = 93.2 \text{ T-M for } 24.84 \text{ GeV/c.}$$
4. Determine resonance strength from previous polarized proton runs at the AGS and select suitable precession angle.

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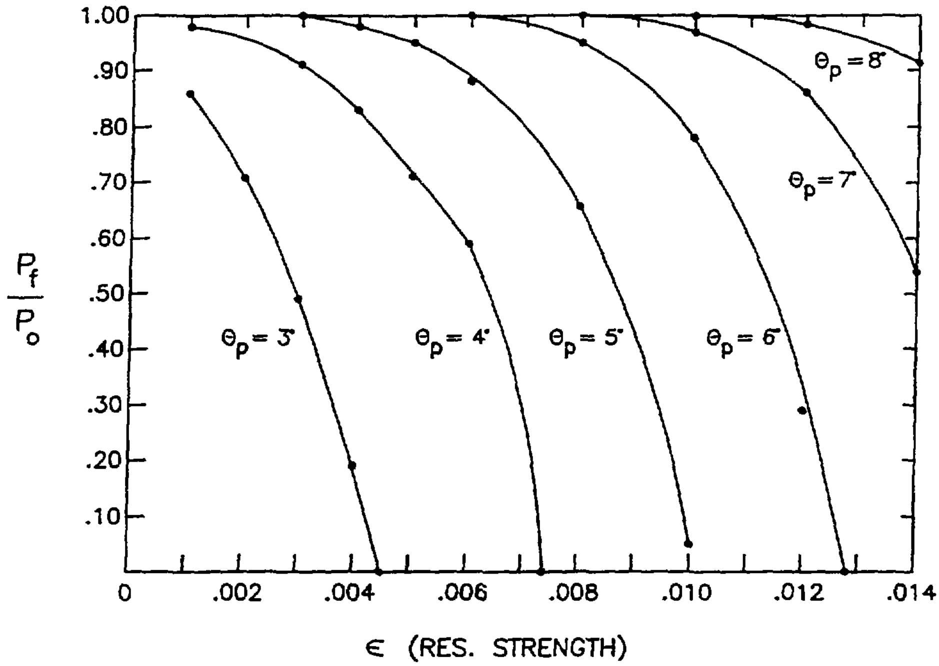

Figure 1: Resonance strengths vs. polarization survival (P_f/P_o) from computer simulations for several different strength snakes.

From Table I we see that a 5° snake can work up to 22 GeV/c with $P_f/P_o \sim 0.76$ and a 6° snake would give $P_f/P_o \sim 1.0$. To get to RHIC injection energy requires an 8° snake. We feel that it would be useful to design a solenoid that can reach 8° or more, but to power it to lower levels from readily available power supplies. This is cost effective and provides an opportunity to do machine studies with partial snakes at energies which are not particularly desirable for physics experiments and/or RHIC.

At the AGS, there are several 4.8 kA 125 V power supplies and after a few iterations we have come up with the following design making use of them.

$$\int_{\theta_p=\pi} B d\ell = 3.752 \text{ P T-M} \qquad \int_{\theta_p=8°} B d\ell = 4.142 \text{ T-M for P} = 24.84 \text{ GeV/c}$$

Choose L = 90" = 2.286 M, B = 1.812 T.
Then, NI ~ 3.4×10^6 amp-turns.

TABLE I

AGS Resonance Strengths and (P_f/P_o) for Various Strength Snakes

$G\gamma$	$P_{(GeV/c)}$	AGS ϵ	P_f/P_o 4°	5°	6°	7°	8°	
7		.0008	.99	1.00	1.00	1.00		NOTE: π = product of all preceeding P_f/P_o
8		.0027	.93	1.00	1.00	1.00		
9		.0045	.78	.965	1.00	1.00		
10		.0011	.98	1.00	1.00	1.00		
11		.0013	.97	1.00	1.00	1.00		
12		.0045	.78	.965	1.00	1.00		
13		.0013	.98	1.00	1.00	1.00		
13-1/2	7.00	--	π=.52		1.00	1.00		
14		.0008	.0008	1.00	1.00	1.00		
15		.0007	.0007	1.00	1.00	1.00		
16		.0010	.0010	1.00	1.00	1.00		
17		.0007	.0007	1.00	1.00	1.00		
18		.0005	.0005	1.00	1.00	1.00		
19		.0005	.0005	1.00	1.00	1.00		
20		.0030	π=.40		1.00	1.00		
20-1/2	10.69	--		1.00	1.00	1.00		
21		.0009		1.00	1.00	1.00		
22		.0010		1.00	1.00	1.00		
23		.0020		1.00	1.00	1.00		
24		.0012		1.00	1.00	1.00		
25		.0026		1.00	1.00	1.00		
26		.0009		1.00	1.00	1.00		
27		.0026		1.00	1.00	1.00		
27-1/2	14.36	--		π=.93		1.00		
28		.0059		.895	.995	1.00		
29		.0030		1.00	1.00	1.00		
30		.0004		1.00	1.00	1.00		
31		.0007		1.00	1.00	1.00		
32		.0009		1.00	1.00	1.00		
33		.0011		1.00	1.00	1.00		
34		.0029		1.00	1.00	1.00		
35	18.30	.0024		1.00	1.00	1.00		↑ 1988 values for ϵ
36		.0040		.98	1.00	1.00		↓ 1986 values for ϵ
36-1/2	19.08	--		π=.82				
37		.0022		1.00	1.00	1.00		
38		.0025		1.00	1.00	1.00		
39		.0054		.93	1.00	1.00		
40		.0024		1.00	1.00	1.00		
41		.0008		1.00	1.00	1.00		
42		.0029		1.00	1.00	1.00		
42-1/2	21.96	--		π=.76	π=.995	π=1.00		↓ Comparison of ϵ measured from $G\gamma$= 36-42 with a Courant calculation for RMS=3.0 mm gave ϵ_M=.37 × ϵ_{calc}.
43		.0055		.92	1.00	1.00	1.00	
44		.0134		0	0	.655	.94	
45		.0126		0	.10	.79	.96	
46		.0059		.92	.995	1.00	1.00	
47		.0108		0	.64	.96	1.00	
47-1/2	24.84	--		π=0	π=0	π=.46	π=.90	

Using OTOKUMPO METALS #6810 29 mm x 29 mm x 16.2ϕ with 0.02" insulation wrap, we can get 76 turns per layer in 90". Use four layers, 304 turns.

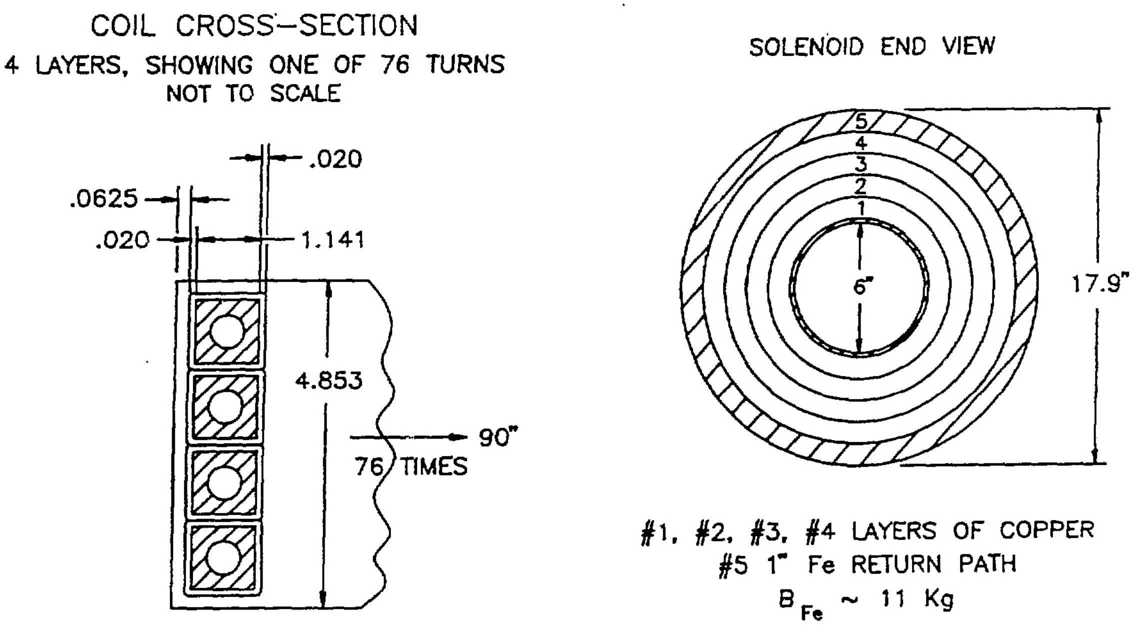

Figure 2: Schematic of coil and end view--not to scale.

$\ell_{\text{Longest layer}} = 260.4'$ $\ell_{\text{Shortest layer}} = 147.9'$ $\bar{\ell} = 204.15'$

$\bar{\ell}_{\text{Total}} = 817'$

$R_L = 2.25$ mΩ $R_S = 1.28$ mΩ $\bar{R} = 1.76$ mΩ $\bar{R}_{\text{Total}} = 7.04$ mΩ

Ramp power supply in 0.6 sec to 9.6 kA.

Average current 4.8 kA.

$E_{\text{Longest}} = 10.8$ V $P_L \sim 52$ kW Duty Cycle = 0.6/3 = 0.2.

$\bar{P}_L = 10.4$ kW in longest circuit $\Rightarrow$ 40 GPM/°C rise.

Allow 8° rise then need 5 GPM = q.

Total length = 817' for four layers, so pressure required:

$$\Delta P = \frac{817}{100} \times 4.84 \times 10^{-2} \frac{q^{1.85}}{d^{4.8655}}, \quad d = 16.2 \text{ mm} = 0.638"$$

$\Delta P = 3.53\ q^{1.85} = 69.3$ psi for all four layers in series.

Total power $\bar{P} = \bar{R}_T\ \bar{I}^2 \times 0.2 = 7.06\ m\Omega \times 4.8^2\ kA \times 0.2 \approx 32.5$ kW and 5 GPM gives an approximately 25°C rise.

$$\text{Inductance } L = \frac{0.32\ a^2 n^2}{6a + 9b + 10c}\ \mu H,$$ where a = 13.943 cm; n = 304 turns;

b = 228.5 cm; c = 12.327 cm.

L = 5.653 mH.

TABLE II

Current Required for Different AGS Conditions

I	Number of Power Supplies	θ_p	P_{AGS}	P_f/P_o
4.8 kA	1	5°	20.3 GeV/c	0.82
4.8 kA	1	6°	16.9 GeV/c	1.00
6.3 kA	2 in parallel	6°	22.0 GeV/c	1.00
8.3 kA	2 in parallel	7°	24.8 GeV/c	0.46
9.5 kA	2 in parallel	8°	24.8 GeV/c	0.90
10.7 kA	Different P.S.	9°	24.8 GeV/c	1.00

With one power supply, could operate the AGS to 16.9 GeV/c passing through many resonances as well as transition. This is lower than desired for physics runs. AGS physics runs likely at 18.5 and 22 GeV/c. So, with two power supplies at 6.3 kA could run program. RHIC would probably want a new supply.

At 6.3 kA $E_{max} = I_R + L\ dI/dt = 104$ V with a 0.6 sec rise time. At 8.3 kA for RHIC, would be voltage limited at about a 1 sec rise time.

We feel that this design will enable us to do a lot of machine studies and to prepare for future physics runs and RHIC at a modest cost. The solenoid and power supply could be commissioned for less than $100,000.