ZGS MACHINE EXPERIMENT REPORT

SURVIVAL OF POLARIZATION ON A LONG FLATTOP

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Abstract

We measured the polarization of a circulating beam of polarized protons at 3.25 GeV/c in the Zero Gradient Synchrotron (ZGS) after circulation times of 20 seconds and 50 seconds. We find that the quantity $\frac{1}{t}\frac{\Delta P}{P} = (-0.31 \pm 0.5) \times 10^{-4}$/sec. The sign of this quantity is negative indicating a net gain in polarization, thus any depolarization is masked by the large systematic error. A one standard deviation statistical error corresponds to a depolarization of $\frac{\Delta P}{P} = 0.50$ in 10^4 seconds or 3 hours. We also directly measured the width of a typical depolarization resonance. We found that the depolarization due to the imperfection resonance ($G\gamma = 6$) decreased by 3 orders of magnitude when we moved 30 gauss away from the peak. Since we stored the beam 400 gauss from this resonance, any measurable depolarization during storage must be due to non-resonance depolarization. These results encourage the possibility of storing proton beams. We plan further experiments to reduce the systematic errors.

ZGS Energy and Location of Resonances

Since we operate the ZGS with a relatively long flattop, we must be far from all imperfection and intrinsic resonances so that resonant depolarization is minimized. Moreover, with a flattop of about a minute, the maximum ZGS momentum is about 4 GeV/c. The first order resonances near this momentum are:

B_{ZGS} (gauss)	Resonance
3680	$G\gamma = 4 + \nu_y$
4769	$G\gamma = 6$
5641	$G\gamma = 7$
5790	$G\gamma = 8 - \nu_y$

In view of this, we operated the ZGS at 5172 gauss which corresponds to a momentum of 3.25 GeV/c.

Vacuum Survival Time of Beam

A beam circulating in an accelerator will lose intensity as:

$$N = N_o e^{-t/\tau}$$

where the decay time, τ, is given by equation [5.2 ISR 300/GS/68-11] to be:

$$\tau = \frac{2.16\,\beta^3\gamma^2}{\bar{\lambda}^2 P\left(\frac{1}{a^2} + \frac{1}{b^2}\right)} \quad .$$

P is the vacuum pressure, a and b are the dimensions of the rectangular vacuum chamber, and $\bar{\lambda} = R/\nu$ is the ratio of the accelerator radius to tune value. For the ZGS:

$$\bar{\lambda} = \frac{R}{\nu} = \frac{27.43\text{M}}{0.8}$$

$$a = 0.35 \text{ M}$$

$$b = 0.06 \text{ M}$$

$$P = 2 \times 10^{-6} \text{ Torr.}$$

This gives a $\frac{1}{e}$ survival time of τ = 37 seconds at 3.25 GeV/c. During the experiment we ran with beam dwell times of 20 seconds and 50 seconds. We found that the measured number of events gave a τ = 63.5 seconds for the 20 second runs and a τ = 61.5 seconds for the 50 second runs. These are all in reasonable agreement considering the uncertainty in the actual ZGS vacuum pressure.

Data Sequencing and Event Rate

For the 20 second dwell time, the ZGS repetition rate was 22.6 seconds. We set up a sequence of eight pulses, the first two pulses spilled the beam within the first second of flattop and the remaining six pulses spilled beam between 19 and 20 seconds. Because of the intensity decay during 20 seconds or 50 seconds, this gave approximately an equal number of events for "early" and "late" spill. The beam polarization was flipped from ↑ to ↓ on alternate pulses in order to remove any systematic bias due to long term drifts in beam polarization. The typical sequence is shown in Fig. 1.

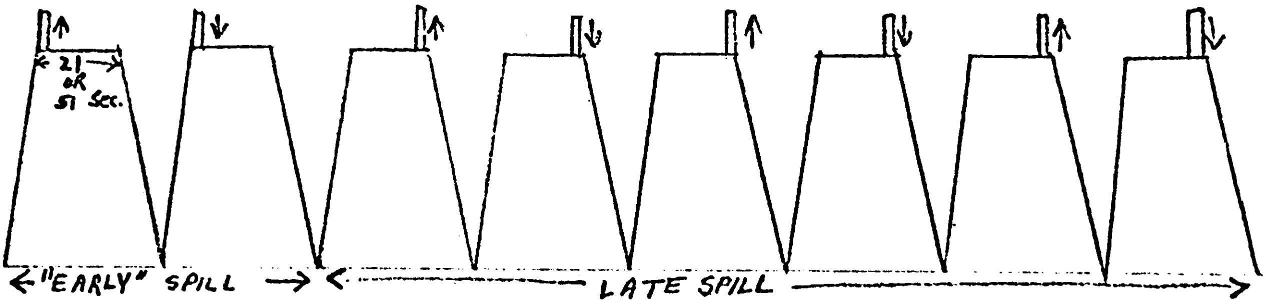

Fig. 1.
Beam Spill and Polarization Sequence

The data was accumulated on a set of eight TSI 1535 scalers with the format shown in Fig. 2.

"Early" Spill

Left	↓
Right	↓
Left	↑
Right	↑

"Late" Spill

Left	↓
Right	↓
Left	↑
Right	↑

Fig. 2.
Data Accumulation Format

We measure the number of events in the left and right arms of a two-arm polarimeter located in the extracted beam. The symbols ↑ refers to spin up and ↓ to spin down. The beam polarization P is obtained from the equation

$$P = \frac{1}{A}\left[\frac{L(\uparrow) + R(\downarrow) - L(\downarrow) - R(\uparrow)}{L(\uparrow) + R(\downarrow) + L(\downarrow) + R(\uparrow)}\right] \cdot$$

where A is the analyzing power or asymmetry parameter. Typical event rates were 50K to 75 K per second per arm for the early spill and 30 K to 60 K per second per arm for the late spill during the 20 second runs. For the 50 second runs, these rates were varied in an attempt to assess the rate dependence of the polarimeter. For the early spill, in this case, rates varied from 100 K to 500 K per second per arm and for the late spill between 30 K and 300 K. During the resonance mapping runs at 20 seconds, rates varied between 10 K and 48 K.

Data Analysis

Using an asymmetry parameter of 0. 179, we calculated the results shown in Table I. These results indicate that there is a rate dependence and that the spread in values allows us to estimate the systematic uncertainty which is much larger than the statistical accuracy. This systematic error in $\frac{\Delta P}{P}$ is about ± 1/2%. In order to better compare the early and late polarizations, we first determined the rate dependence and then took the values of polarization at equal rate points for the early and late spills.

Table I

20 Second Flattop

Run No.	EARLY		LATE	
	Polarization	Rate/Pulse/Arm	Polarization	Rate/Pulse/Arm
1	.7462±.0027	75000	.7743±.0029	42000
2	.7460±.0027	73000	.7757±.0027	47000
3	.7561±.0028	75000	.7726±.0025	57000
4	.7448±.0030	78000	.7651±.0025	67000
5	.7448±.0030	69000	.7723±.0025	58000
6	.7489±.0042	69000	.7627±.0033	57000
7	.7574±.0035	51000	.7703±.0028	41000
8	.7627±.0039	41000	.7563±.0031	24000
9	.7739±.0038	42000	.7691±.0031	29000
10	.7772±.0038	41000	.7623±.0031	31000
11	.7651±.0040	43000	.7681±.0033	32000
12	.7717±.0035	47000	.7625±.0032	29000
Σ1 - 6	<.7478±.0010>	<73.2K>		
Σ1 - 7			<.7704±.0010>	<52.7K>
Σ7 - 12	<.7680±.0014>	<44.2K>		
Σ8 - 12			<.7637±.0014>	<29.0K>

50 Second Flattop

Run No.	EARLY		LATE	
	Polarization	Rate/Pulse/Arm	Polarization	Rate/Pulse/Arm
1	.7173±.0047	320000	.7620±.0100	87000
2	.7364±.0091	198000	.7512±.0188	73000
3	.7352±.0075	195000	.7768±.0163	65000
4	.7540±.0056	139000	.7650±.0116	90000
5	.7490±.0044	102000	.7496±.0120	31000
	.7540±.0023 Extrapolation from Fig. 4.	69.2K	<.7609±.0053>	<69.2K>

We first consider the 20 second flattop data. Notice that the early data falls into two rate bins: runs 1 - 6 with a rate of 69 - 78K/pulse/arm and runs 7 - 12 with a rate of 41 - 51K/pulse/arm. As shown in Fig. 3, we took the average of runs 1 - 6 and of runs 7 - 12 and plotted these as a function of rate. We handled the late data in a similar fashion. As can be seen the two lines intersect at a rate of 44000 counts/arm/pulse. This gives us the value of $\frac{\Delta P}{P} = 0.0 \pm .0011$ or for the 20 second interval a $\frac{1}{t}\ \frac{\Delta P}{P} = (0.0 \pm 0.55) \times 10^{-4}/\mathrm{sec}$.

For the 50 second flattop, we increased spill rates in order to get a better determination of the rate dependence. Fig. 4 shows the dependence for the early spill. The late spill showed no clear trend and the average polarization was 0.7609± .0053 for a rate of 69.2K/pulse/arm. At the 69.2K rate we find for the early spill a polarization of .7540± .0023 where the error is the rms value of the five runs. We then have that the depolarization is

$$\frac{\Delta P}{P} = \frac{-.0069 \pm .0058}{.7575 \pm .0021} = -.0091 \pm .0061$$

$$\text{and } \frac{1}{t}\ \frac{\Delta P}{P} = (-1.8 \pm 1.2) \times 10^{-4}/\mathrm{sec}.$$

Averaging the 20 second and 50 second data we obtain the weighted average

$$\left\langle \frac{1}{t}\ \frac{\Delta P}{P} \right\rangle = (-0.31 \pm .50) \times 10^{-4}/\mathrm{sec}$$

where the minus sign indicates an increase in polarization from early to late spill. We see that our systematic error of $\frac{\Delta P}{P} = 1/2\%$ would give a depolarization of $\frac{\Delta P}{P} = 1.4 \times 10^{-4}$ in 35 seconds which would mask our results. However, this null result is encouraging to the possibility of the storage of polarized beam. Further experiments will be done to reduce the systematic errors. The statistical error is at the level of $\frac{\Delta P}{P} = 0.50$ in 10^4 seconds, which would give useful polarization for this period of several hours.

The measurements for mapping the $G\gamma = 6$ resonance are shown in Table II and the results are summarized in Fig. 5.

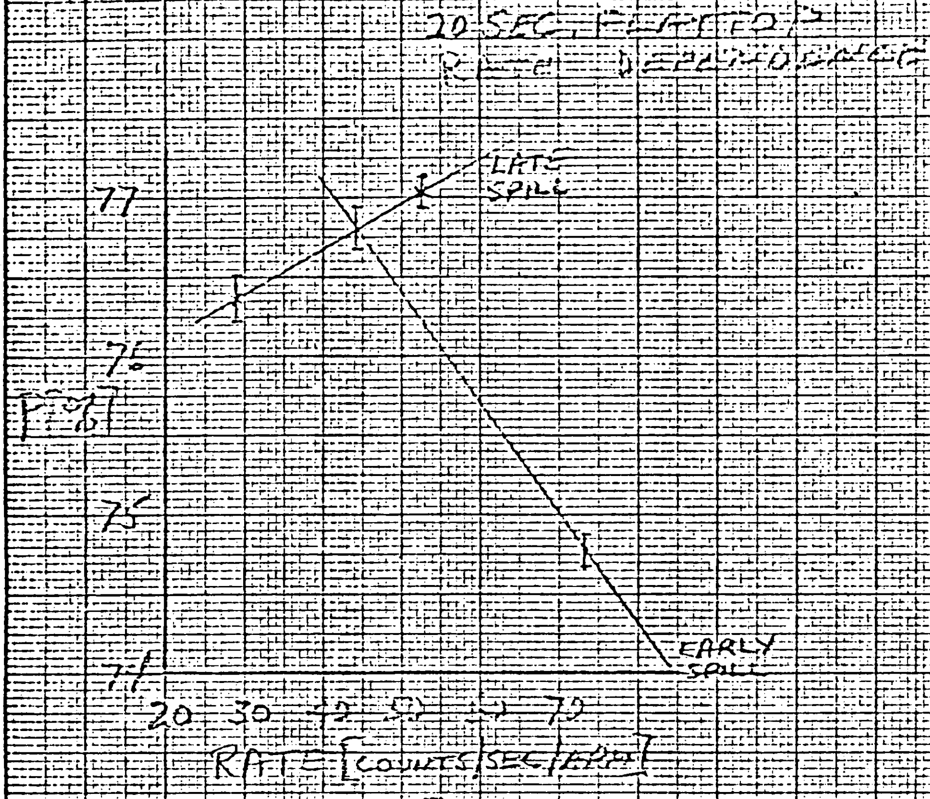
20 SEC. FLATTOP
RATE DEPENDENCE
LATE SPILL
EARLY SPILL
77
76
75
74
P [%]
20 30 70
RATE [COUNTS/SEC/AREA]

FIG. 3

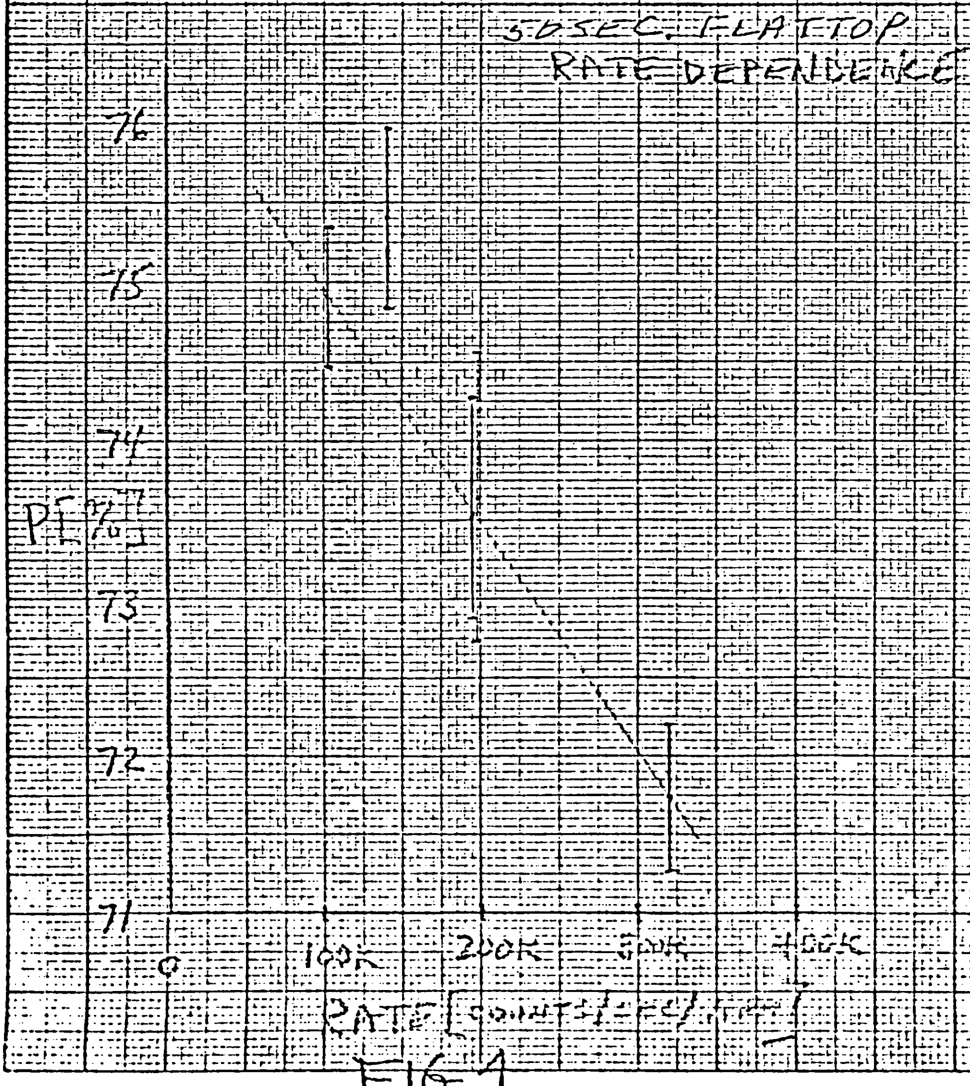
30 SEC. FLATTOP
RATE DEPENDENCE
76
75
74
73
72
71
P [%]
0 100K 200K 300K 400K

FIG. 4

Table II

B (Gauss)	Polarization Early	Polarization Late	P initial*	ΔP Early	ΔP Late	<early, late>	<average over B>	$\left\langle \frac{1}{t} \frac{\Delta P}{P_o} \right\rangle$
4771	.0947 ±.0067	-.0014 ±.0068	(.7961) ±.0063	.7014 ±.0092	-	.7222 ±.0091	.6844 ±.0066	(6.8± .07)x10^{-}
4771	.1681 ±.0075	-.0033 ±.0067	(.7961) ±.0063	.6280 ±.0098	-	.6466 ±.0095		
4822	.7414 ±.0074	.7693 ±.0052	.7398 ±.0078	-.0016 ±.0108	-.0295 ±.0094	-.0018 ±.0005	-.0018 ±.0005	-(1.8± 0.5)x10^{-}
4800	.7820 ±.0044	.7730 ±.0039	.7825 ±.0047	.0005 ±.0064	.0095 ±.0061	.0005 ±.0003	.0002 ±.0003	(2.0± 3.0)x10^{-}
4800	.8091 ±.0069	.8111 ±.0062	.8090 ±.0073	-.0001 ±.0100	-.0021 ±.0096	-.0001 ±.0005		
4785	.7644 ±.0050	.0072 ±.0050	.8078 ±.0053	.0434 ±.0073	.8006 ±.0073	.0440 ±.0004	.0442 ±.0003	(4.4± .03)x10^{-}
4785	.7691 ±.0057	.0023 ±.0049	.8131 ±.0060	.0440 ±.0083	.8108 ±.0077	.0443 ±.0004		
4792	.7891 ±.0054	.7258 ±.0046	.7927 ±.0057	.0036 ±.0079	.0669 ±.0073	.0038 ±.0004	.0038 ±.0004	(3.8± 0.4)x10^{-}
4755	.8066 ±.0064	.7997 ±.0062	.8070 ±.0068	.0004 ±.0093	.0073 ±.0092	.0004 ±.0005	.0004 ±.0005	(4.0± 5.0)x10^{-}
4763	.8102 ±.0060	.8068 ±.0045	.8104 ±.0063	.0002 ±.0087	.0036 ±.0077	.0002 ±.0004	.0002 ±.0004	(2.0± 4.0)x10^{-}
4768	.8018 ±.0060	.7896 ±.0054	.8025 ±.0064	.0007 ±.0088	.0129 ±.0084	.0007 ±.0005	.0007 ±.0005	(7.0± 5.0)x10^{-}
4780	.1375 ±.0064	.1015 ±.0063	(.7961) ±.0063	.6586 ±.0090	-	.6781 ±.0090	.6781 ±.0090	(6.8± .09)x10^{-}

* P initial is calculated on the assumption that the depolarization is linear in time between 1.22 second and 22.5 second. For those runs (13a, 13b, 23) where the polarization is essentially completely lost in 1.22 second, we have used the average of the other runs and the error is the average of the error of these runs.

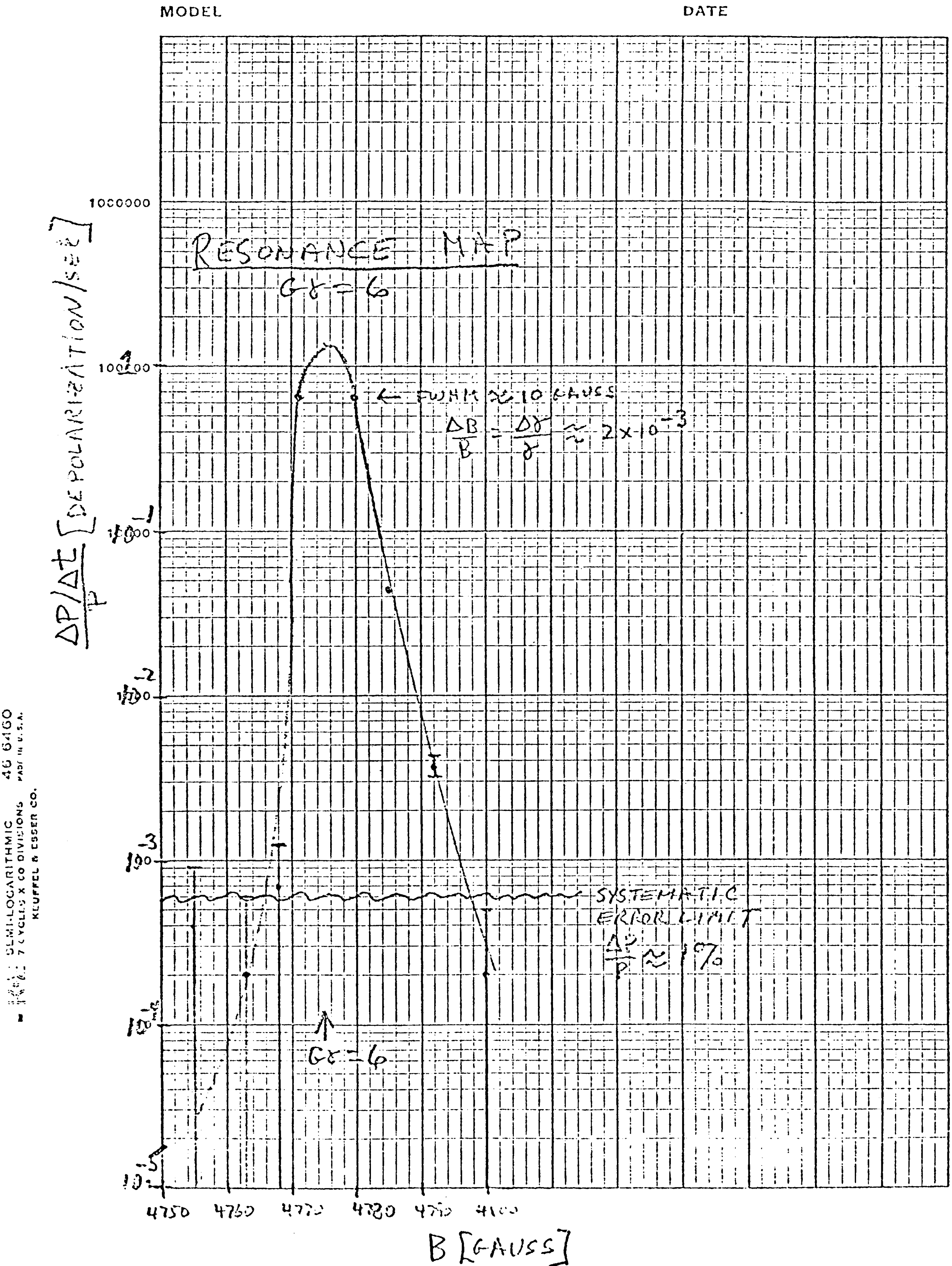
MODEL
DATE
RESONANCE MAP
Gγ = 6
ΔP/Δt / P [DEPOLARIZATION/sec]
← FWHM ≈ 10 GAUSS
ΔB/B = Δγ/γ ≈ 2×10^-3
SYSTEMATIC ERROR LIMIT
ΔP/P ≈ 1%
Gγ = 6
4750
4760
4780
B [GAUSS]
SEMI-LOGARITHMIC 46 6460
7 CYCLES X 60 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

FIG. 5