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Polarization Measurement Using the Internal Polarimeter without a measuring porch

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Introduction

A serious problem associated with acceleration of polarized protons in the AGS occurs after the beam has been successfully tuned through all of the depolarizing resonances to full energy and then that polarization is observed to decrease--perhaps dramatically. How can one quickly determine which of the 30 some resonances are destroying the polarization? One approach which has been tried is to use the internal polarimeter without going to the trouble of building a fixed energy porch in the magnetic cycle to make the measurements. This immediately gives (using the five gates available in that system) measurements of the polarization at five energies in the cycle--hence this technique is referred to as a polarization energy scan. Of course, what is actually measured is the asymmetry in the counting rate. The proportionality between this and the polarization (the analyzing power) is both energy dependent and not well known.

[Pol = (Asym)/(Anal. Power)]

The fact that to obtain polarization as a function of energy requires dividing the experimental result by another function of energy is primarily a problem of interpretation once away from low energies where the analyzing power is a steep function of energy.

There is a more worrisome effect associated with the internal polarimeter--namely the target used (a 6 mil nylon string in this run), also causes the size of the beam to grow in both traverse planes. Since the strength of an intrinsic resonance for a particle is proportional to the amplitude of that particle's betatron oscillations, the effect of string insertion is to increase the amount of depolarization observed at those intrinsic resonances occurring after insertion time. The normal measurement on a magnetic flat porch avoids this problem simply by positioning the porch to avoid all resonances and by not measuring later in the cycle.

Experimental Hypothesis and Procedure

The experiment described attempted to determine the importance of this emittance increase due to the target insertion on the polarization being measured. The method was to measure polarization (using the energy scan technique) on 5 intervals (gates) positioned between the intrinsics: $G\gamma = 24-\nu$, $12 + \nu$, $36-\nu$, and $24 + \nu$. The gates are sketched in Fig. 2. The "in" time of the string was varied from much earlier than the earliest gate to just before the final gate. In this way the beam size at each intrinsic was varied over a wide range. The beam size was measured using the IPM for each situation.

Table I gives the gates chosen and the analyzing powers used in the analysis. The fact that each gate spans an interval in momentum or analyzing power is handled by simply taking the central value.

Beam size is not expected to affect the imperfection resonances so by taking the ratio of the polarization measured before and after a given intrinisic resonance for a series of beam sizes, one hopes to be able to extrapolate that ratio to the normal beam size (string out) and hence quantify how strongly the presence of the string contaminates the polarization measurement.

Results

Table II and Figure 1 give the measured polarizations using the numbers from Table I. Some fraction of the internal beam was extracted to the D line external polarimeter throughout this period, and that measurement is included in the results. The extraaction efficiency varied with string time however.

Table III gives the beam vertical size as measured by the the Ionization Profile Monitor. The standard IPM analysis package (IPMPL) is used to fit the projection to a Gaussian distribution. The standard deviation (σ) of that Gaussian is listed. The fits are reasonable.

Figure 2 gives in a "mountain range" format some examples of beam size vs time in the acceleration cycle for several different string insertions times.

Finally, Table IV gives the ratios of polarization from Table II for gate C/gate B (bracketing $12 + \nu$), D/C ($36-\nu$), E/D ($24 + \nu$), and External/E. Figure 3 plots this for resonances $36-\nu$ and $12-\nu$ against beam size at these resonances.

Analysis

Figure 3 shows in a qualitative way the expected reduction in polarization at an intrinsic as the beam size is increased. One theoretical function for this follows from the paper by E.D. Courant and R.D. Ruth, "The Acceleration of Polarized Protons in Circular Accelerators," BNL 51270. For a fast jump through a resonance, $P_f/P_i \simeq (\delta^2+\varepsilon^2)$, where δ is the tune jump and ε is the resonance strength. For our purpose, with ε assumed proportional to beam size and δ fixed in this experiment, this implies the points in Fig. 2 should fall on a curve given by $(1-kx^2)/(1+kx^2)$, where x is the beam size and k depends on the details of the particular resonance. A family of such curves is sketched on Fig. 3. Again, there is crude agreement, but the data shows a sharper fall than the function. In particular, one gets little, and apparently pessimistic, guidance from the curves on the extrapolation to "no blow-up" beam sizes. A close look at Fig. 1 shows some unexpected behavior. The general trend in each gate is for polarization to increase as the beam size decreases--as expected. However, gate A (which follows (0+ν) shows a significant polarization loss with beam size reduction (6.8 cm → 3.8 cm). Most of the other gates also show a polarization drop for the smallest beam size measurement. Since there is no expectation of such a polarization drop one suspects there may be a systematic problem in the measuring technique. In particular the final measurement for each gate occurs with the internal polarimeter target swinging into position just at the start of the gate. Neither the detailed motion of the target as it swings in (damped oscillation?) nor the effect of this on the measured polarization is known. For "porch" operation, the interval is avoided. If these "swing" values are discarded and the value from the previous run used in the ratio, the shaded points on Fig. 3 result. One other systematic effect inherent in this technique is a large change (x10) in beam density at the string during the course of the measurement, and so presumably a change in counting rates at the scintillation counters. There is, however, no indication of a problem here; if there were, it would also affect the porch measurements and vary with momentum since the beam size changes dramatically over the cycle even with no target present.

Summary - Conclusions

The use of the internal polarimeter in an energy scan mode can cause a significant polarization loss at the 36-ν and 24+ν intrinsic resonances; the loss grows as the beam size grows. Attempts to minimize this effect by inserting the target just prior to a measurement appear to systematically reduce the reported polarization for that measurement. Presumably the measured polarization also depends on the beam size present without the target inserted. That is, the results depend on other machine parameters like the emittance early in the acceleration cycle which change with time. The use of the energy scan technique to find points of polarization loss is a tricky business. Of course it should also be admitted that other parameters may have been changing during the run adding unknown systematic errors to the result. The polarized machine was not too stable.

TABLE I.

Gates:	A	B	C	D	E
Start Time $\frac{ms}{T\emptyset}$	250	320	400	505	590
End Time $\frac{ms}{T\emptyset}$	310	385	480	570	650
Centrol Momentum GeV/c	6.7	9.4	23.4	15.7	18.4
Analyzing Power	.049	.038	.027	.020	.018
	↑	↑	↑	↑	↑
$G\gamma$ =	$0 + \nu$	$24 - \nu$	$12 + \nu$	$36 - \nu$	$24 + \nu$

TABLE II: Polarization (%)

String In Time	Gate Run # PPP	A	B	C	D	E	Ext. Pol.
100	32	72.0±.8	63.9±1.1	58.1±1.1	48.5±2	13.9±2.2	21.2±1.9
100	38	71.8±.8	63.1±1.1	56.7±1.1	48.0±2	15.6±2.2	19.1±2.2
150	40	67.8±.8	64.7±1.1	60.7±1.1	45.0±2	17.8±2.2	15.4±2.0
170	39						
180	30	62.9±.6	(64.7±.8)	(58.5±1.1)	(53.0±1.5)	36.7±2.2	29.8±1.4
180	31	65.5±.8	65.5±1.1	63.7±1.1	50±2	28.9±2.2	26.4±1.8
230	33						
230	34	65.5±1.2	65.8±.8	63.0±1.1	55.0±1.5	31.7±2.2	28.5±1.5
350	35	---	---	61.1±1.1	60.5±1.5	38.3±1.7	34.5±1.3
445	36	---	---	---	54.5±1.5	52.2±1.7	44.4±1.2
530	37	---	---	---	---	45.6±2.	49.6±1.3
None	22	---	---	---	---	---	45
None	42	---	---	---	---	---	35

TABLE III: Beam Size at Intrinsics

Sigma (mm)

String in Time	Run # PPP	0 + ν	12 + ν	36 - ν	24 + ν
(ms from T_o)					
100	32	6.7 ± .1	6.8 ± .2	6.35	6.5 ± .1
100	38	6.85	6.9 ± .2	6.3 ± .2	6.6 ± .2
150	40	5.0 ± .2	6.4 ± .2	6.0	6.15
170	39	3.65 ± .1	6.0 ± .1	5.75 ± .1	6.0 ± .1
180	30	3.8	5.7 ± .1	5.65	5.95
180	31	3.75 ± .1	5.9 ± .2	5.6	5.95
230	33	3.8	4.5 ± .1	5.0	5.15
230	34	3.75	4.45 ± .1	4.7	5.25 ± .1
350	35	3.65	2.1	3.75	4.45
445	36	3.65	2.1	1.9	3.25
530	37	3.6	2.1	1.85	1.8
None	22	3.8 ± .1	2.15	1.95	1.8
None	42	3.7 ± .1	2.15	1.95	1.85

Error estimate ± .05 unless noted.

TABLE IV: Polarization Ratio

In Time ms from T_o	Run # PP	(12 + ν) C/B (±.02)	(36 − ν) D/C (±.04)	(24 + ν) E/D (±.05)	Ext/E
100	32	.91	.84	.29	1.5 ± .3
100	38	.90	.85	.33	1.2 ± .2
150	40	.94	.74	.40	.87 ± .16
180	30	(.90)*	(.91)*	(.69)*	.81 ± .06
180	31	.97	.79	.58	.91 ± .09
230	34	.96	.87	.58 ± .04	.90 ± .08
350	35		.99	.63 ± .03	.90 ± .05
445	36			.96 ± .04	.85 ± .04
530	37				1.09 ± .06

* Slightly different gate widths.

Polarization (internal polarimeter except 18,5 GeV/c)

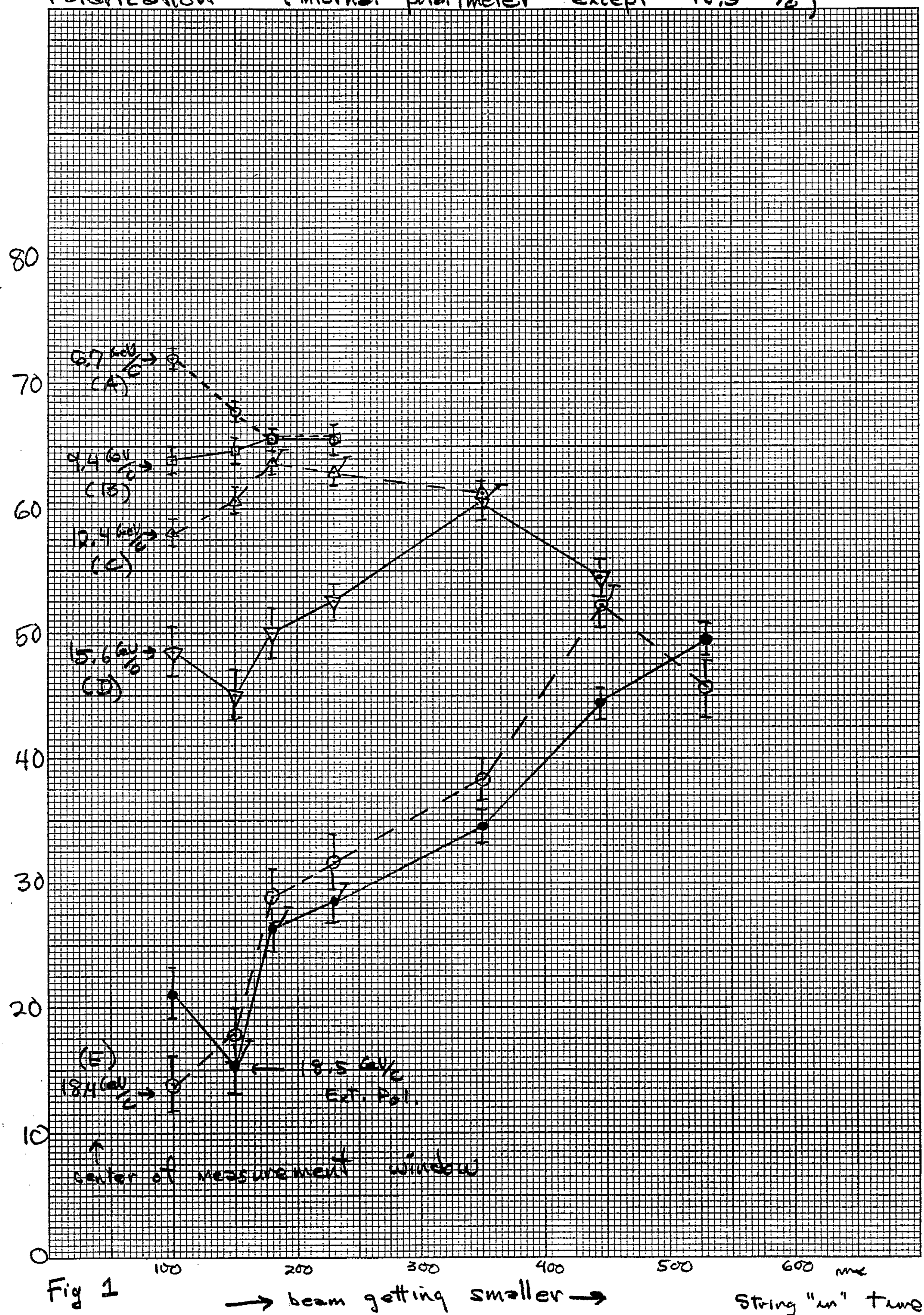

Fig 1

Vertical Beam Growth with time for various insertion times

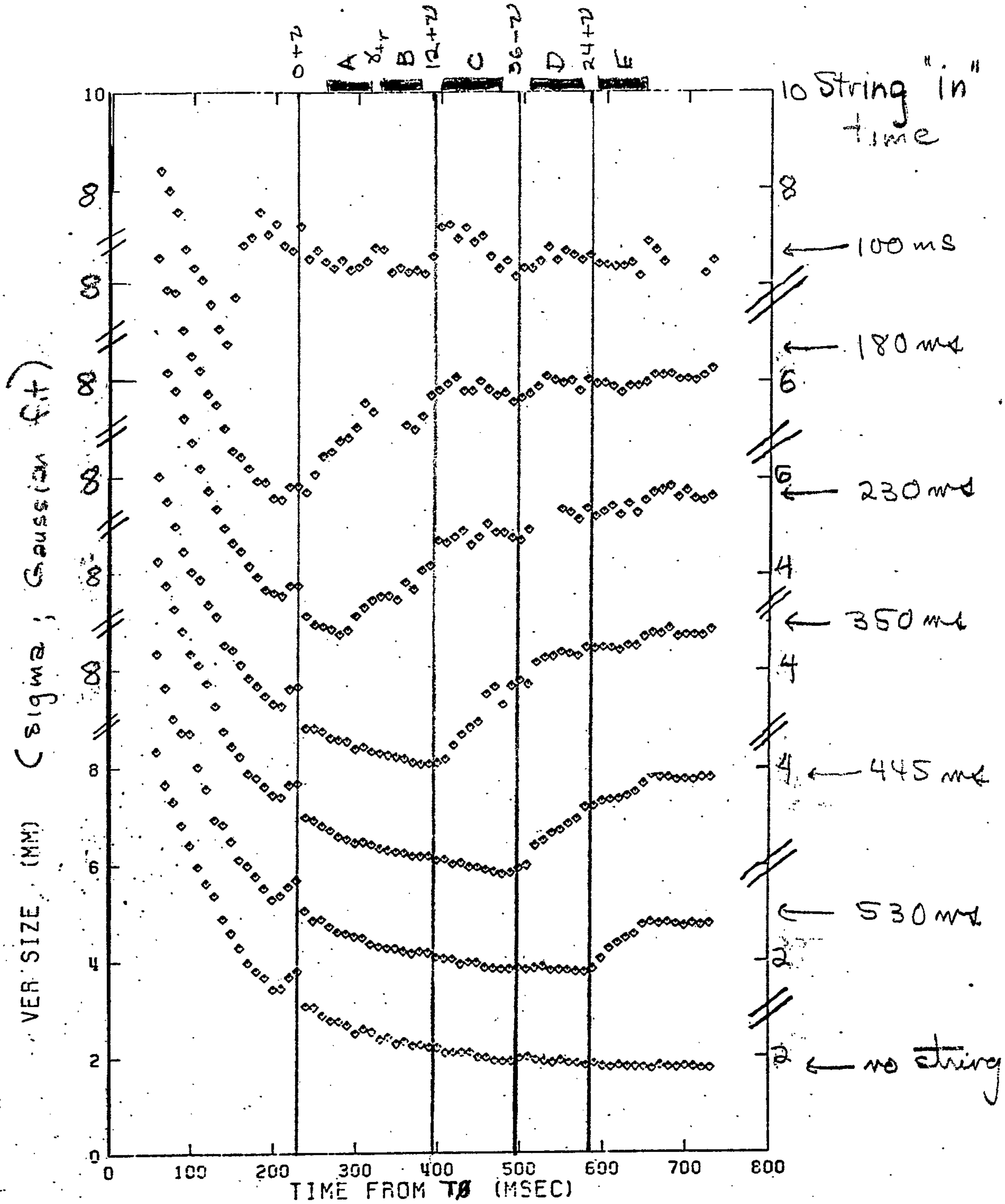

Figure 2

(2 mm shift of vert. scale between traces)

Polarization loss vs Beam Size

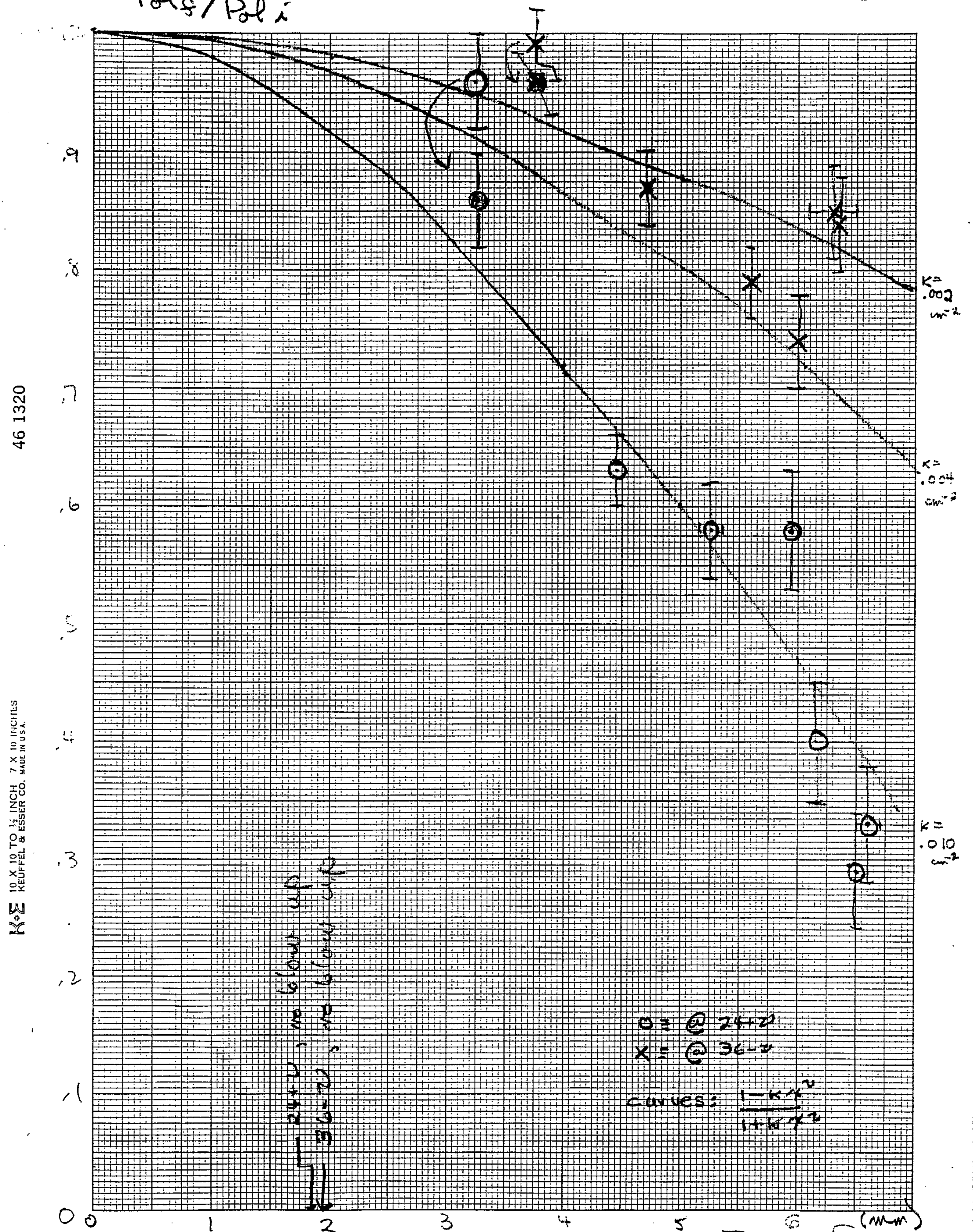

Figure 3