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Evaluation of the Possibility of Cryotrapping Helium Jet by Means of a Parallel Stream of Hydrogen Condensing on a 4.2°K Surface

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Summary

We have developed a method for evaluation of trapping for a pulsed stream of gas. This method was used for measuring the cryotrapping helium by hydrogen. We find no cryotrapping for the range of variables used within the accuracy of our measurements (±20%). We have also obtained a great deal of data which will be helpful in designing the vacuum system for the helium jet target.

INTRODUCTION

Measurements of pp and pd interactions have been successfully carried out in the internal beams of accelerators.[1,2] These measurements were made using gas jet targets inside the machine vacuum chamber.[3] One of the main problems in the construction of the jet target is the capture of the gas so as to maintain adequate accelerator vacuum. In addition to the main accelerator vacuum system, a special trapping system for the gas stream is necessary. Most of the gas stream is captured by the trapping system while the remaining gas must be pumped out by the accelerator vacuum system. For the hydrogen and deuterium jets a cup at liquid helium temperature is successfully used as a trapping system.[3]

For the investigation of the pHe interaction in the internal beam of the accelerator, a He jet target is necessary. To maintain the adequate vacuum, an efficient method of trapping the helium is required.

The usual cryogenic techniques for pumping helium from vacuum volume are the following:

1) Adsorption by a solid adsorber, e.g.,a molecular sieve at $4.2^{o}K$.[4]

2) Adsorption by layers of condensing gases, e.g., CO_2 also at $4.2^{o}K$.[5]

3) Cryotrapping. This consists of trapping molecules of a non-condensing gas (helium) by the molecules of a condensing gas (hydrogen) at $4.2^{o}K$.[6]

Usually the pumped gas fills the vacuum volume uniformly. In the present case, however, we must pump a gas stream whose density is 4 to 5 orders greater than that of the surrounding evacuated volume. As no data exist for this special case, it must be found experimentally.

This paper describes the results of measuring the cryotrapping efficiency for trapping a helium stream by a parallel hydrogen stream condensing on a surface at $4.2^{\circ}K$.

APPARATUS

The measurements were performed on the hydrogen, deuterium jet target facility located at the Fermilab internal target area.

Figure 1 shows a sketch of the apparatus. Gas goes from the cylinder labeled (1), through a regulator (2), to the solonoid valve (3). When the valve is open, the gas goes through a capillary (4), 2m long and 1mm in diameter. While passing through the capillary, the gas is cooled $20\text{-}25^{\circ}K$ before being injected through a 0.3 mm diameter nozzle into the main accelerator vacuum chamber.

The isolation valves (6 and 7) at the ends of the C0 straight section containing the jet target enclose a volume of $0.76\ m^3$.

A six channel recorder (14) was used for recording pressure changes in the vacuum chamber as well as the opening and closing of solonoid valve (SV).

Cryotrapping coefficients were measured for various ratios of hydrogen and helium in the gas stream. The gas temperature at the nozzle was held at $20^{\circ}K$ and the time duration of SV was held constant at 50 msec. The dependence of the gas pressure into

vacuum volume on the gas temperature and pulse duration was also determined from additional measurements. The pressure was measured by two ionization gauges (11 and 12) and at the two ion pumps (9). Table 1 lists the parameters used in all the runs that were made. In these tests, the gases were mixed and injected through one nozzle.

METHODS AND RESULTS

The cryotrapping coefficient can be defined by

$$K = \frac{V_o - V_1}{V_o}$$

where:

V_o is the helium volume injected into the vacuum chamber.

V_1 is the helium volume pumped by the accelerator vacuum system within the C0 straight section.

The difference $V_o - V_1$ is the volume of gas cryotrapped.

The volume of gas flowing through the nozzle is given in cm^3 at STP by teh following relation

$$V_o = \frac{\pi D^2}{4}\left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}}\left(\frac{2\gamma}{\gamma+1}\right)^{1/2}\left(\frac{m}{KT_o}\right)^{1/2} p_o \rho \Delta\tau \qquad (1)$$

where,

D - nozzle diameter (0.03sm)

γ - adiabatic expansion coefficient ($\gamma_{He} = 1.67$, $\gamma_{H_2} = 1.4$)

M - molecular weight($M_{He} = 6.68 \cdot 10^{-24}$g, $M_{H_2} = 3.34 \cdot 10^{-24}$g)

K - Boltzman constant ($K = 1.38 \cdot 10^{-16}$ erg/grad

T_o- gas temperature before nozzle ($T = 20^oK$)

P_o- pressure of the gas before the nozzle ($dyne/sm^2$)

ρ - gas density at STP($\rho_{He} = 0.178 \cdot 10^{-3}g/sm^3$; $\rho_{H_2} = 0.09 \cdot 10^{-3}g/$ 3

ΔT- opening time of the valve before the nozzle (SV)

For pure helium the formula gives

$$V_{He} = 6.90\ P_o \qquad 1a$$

For pure hydrogen

$$V_{H_2} = 8.92\ P_o \qquad 1b$$

Using the above two expressions we obtain the following result

$$V_{He} = (8.92 - 2.02\ R)\ P_o' \qquad 1c$$

where

V_{He} is the helium volume in the mixture P_o' is the pressure before the SV in kg/cm^2 and R is the percent of helium in the mixture.

The volume of gas given by formula 1 depends on the gas pressure just before the nozzle. In the present apparatus, however, we are unable to measure this pressure. We use, instead, the pressure measured just before VS at the entrance to the capillary. This leads to an error which is approximately ± 20% in the volume calculated from Eqs. 1a, 1b, and 1c. For this system pumping out time was measured as a function of helium volume, V (see Fig. 2, curve 1). To get this dependence, pure helium was used in the nozzle. The helium quantity was changed by varying the pressure before the valve SV. The temperature before the nozzle was maintained at $20^{\circ}K$. The time that the valve, VS,remained open was 50msec. The time t of pumping out of the helium was the time between the moment of opening of VS and the moment of obtaining pressure P_o at the vacuum gauge 1. The pressure P_o was chosen between the limits Pmin and Pmax to be independent of the frequency of cycle and the quantity of helium injected. Here Pmin and Pmax are pressures in the vacuum chamber before injection and at the

moment of injection (see Fig. 3). The experiment was carried out with the following ratios of hydrogen to helium: 9:1, 20:1, 50:1, 100:1.

If there is cryotrapping, part of the helium from the jet is trapped and the rest diffuses into the vacuum chamber and is pumped out by the accelerator vacuum system. Using this pumping time, we can estimate how much helium went into the accelerator vacuum and how much remained in the cryotrap, i.e., we can find the coefficient of cryotrapping.

One can see from Fig. 3 that the upper part of curve 2 practically coincides with curve 1. This means that in this region, all the helium injected with the hydrogen was pumped only by the vacuum system of the accelerator. Helium cryotrapping by hydrogen was not observed within the experimental errors. The experimental setup, unfortunately, did not give us the possibility of covering a large region of He volumes.

This method also permitted us to determine the efficiency of trapping pure hydrogen from the jet using the cryopump at $4.2^{\circ}K$. This was done as follows: In Fig. 2, the pumping time is shown as a function of the quantity of hydrogen injected into the vacuum chamber. The dashed line shows the linear extrapolation of curve 1 into the small volume region. The pumping speed of hydrogen and helium by the vacuum system were assumed to be equal. The point a corresponds to the injected volume, $V_o = 6.6\ cm^3$. Point b corresponds to the volume pumped by the vacuum system, $V_1 = 0.17\ cm^3$. The volume of hydrogen absorbed from the jet is $V_o - V_1 = 6.43\ cm^3$ with a corresponding cryotrapping efficiency

of 0.97.

The accuracy of this method of determining the cryotrapping efficiency becomes greater as the pumping time of the condensing gas (hydrogen) becomes smaller in comparison with the pumping time of the non-condensing gas (helium). Figure 3 shows the change of pressure in the vacuum chamber with time. For the injection of pure hydrogen V = 17.9 cm^3 (curve 1) and helium V = 2.04 cm^3 (curve 2), the time that SV was open was the same.

In spite of the fact that the volume of Helium injected into the chamber was 9 times less than the volume of hydrogen, the pumping time for hydrogen is only about 10% of the time for pumping helium. The same figure shows the possible region for the curve that corresponds to a mixture of 18 cm^3 H_2 and 2.18 cm^3 He. The reason why there is a region of uncertainty is a result of the fact that the true ratio of H_2 and He in the vacuum chamber is not know. The upper boundry curve 3a was drawn assuming that in the vacuum chamber all the residual gas is hydrogen. The lower curve 3b corresponds to helium being the residual gas. Therefore, the true curve lies somewhere between the two boundary cruves.

For these measurements, we used pressure gauges calibrated to nitrogen. To obtain the real pressure of hydrogen and helium in the vacuum chamber, the coefficient for H_2 and He were 2.4 and 4.8 respectively.

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FIGURE CAPTIONS

Fig. 1 Experimental setup and part of the accelerator vacuum that were used for this experiment. Components of the system were: 1) gas cylinder, 2) regulator, 3) solonoid valve SV, 4) capillary, 5) capillary-nozzle, 6,7) main ring isolation valves, 8) diffusion pumps type BB5-62A with a capacity of 1000 ℓ/sec, 9) ion pumps with a capacity of 600 ℓ/sec, 10) cryogenic pump for trapping the hydrogen and deuterium jet, 11,12) ion gauge with cold cathode, 13) vacuum gauge readout, Series 236 model 02, 14) 6 channel strip chart recorder (Bruch Mark 260), 15) ion pump vacuum gauge. The scale of the vacuum chamber is in cm.

Fig. 2 Pumping time for the C0 section of the accelerator vacuum chamber by the vacuum system during jet running as a function of injected volume and gas type. The cruves are 1, hydrogen; 2, helium; 3, hydrogen with different percentages of helium (by volume): X-10%, 0-4.76%, Δ-2.07%, -1.0%. The pumping time is defined from the moment of opening the valve SV to the moment of reaching the pressure $P_o = 1.5 \cdot 10^{-5}$ torr.

Fig. 3 The pressure variation (measured with pressure gauge 11 in Fig. 1) in the accelerator vacuum chamber during the jet target runs. 1) injection of 17.9 cm^3 hydrogen every 6.7 sec, 2) injection of 2.04 cm^3 helium every 13.3 sec, 3) injection of the mixture 18 cm^3 hydrogen and 2.18 cm^3 helium every 13.3 sec.

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Table #1

Run	A			B			C			D			E			F			G			H		
T before nozzle	300°K / 100% He			20°K / 1.0% He			20°K / 100% He			20°K / 2.07% He			20°K / 4.75% He			20°K / 10.1% He			20°K / 100% H_2			300°K / 100% He		
#	p before V, atm	τ open V, μsec		#	p	τ	#	p	τ	#	p	τ	#	p	τ	#	p	τ	#	p	τ	#	p	τ
1	0.102	50		1*	0.51	50	1*	.1	50	1*	.51	50	1*	.51	50	1*	.51	50	1*	.51	50	1	.102	50
2	0.102	100		2*	1.0	50	2	.1	100	2	.51	100	2	.51	100	2*	1.0	50	2	.51	100	2	.51	50
3	0.102	200		3*	1.5	50	3	.1	200	3	.51	200	3	.51	200	3*	1.5	50	3	.51	200	3	1.0	50
4	0.102	300		4*	1.97	50	4	.1	300	4	.51	300	4	.51	300	4*	1.94	50	4	.51	300	4	1.5	50
5	0.204	50		5*	2.52	50	5*	.2	50	5*	1.0	50	5*	.88	50	5*	2.51	50	5*	.99	50	5	.68	50
6	0.204	100		6	2.52	100	6	.2	100	6	1.0	100	6	.88	100				6	.99	100	6	.51	50
7	0.204	200		7	2.52	200	7	.2	200	7	1.0	200	7	.88	200				7	.99	200	7	.274	50
8	0.204	300		8	2.52	300	8	.2	300	8	1.0	300	8	.88	300				8	.99	300	8	.068	50
9	0.34	50					9*	.295	50	9*	1.5	50	9*	1.3	50				9*	1.56	50	9	.034	50
10	0.34	100					10	.295	100	10	1.5	100	10	1.3	100				10	1.56	100	10	.102	50
11	0.34	200					11	.295	200	11	1.5	200	11	1.3	200				11	1.56	200	11	.102	100
12	0.34	300					12	.295	300	12	1.5	300	12	1.3	300				12	1.56	300	12	.102	200
13	0.478	50					13*	.51	50	13*	2.0	50	13*	2.0	50				13*	2.01	50	13	.102	300
14	0.478	100					14	.51	100	14	2.0	100	14	2.0	100				14	2.01	100	14	.102	400
15	0.478	200					15	.51	200	15	2.0	200	15	2.0	200				15	2.01	200	15	.102	400
16	0.478	300					16	.51	300	16	2.0	300	16	2.0	300				16	2.01	300	16	.102	300
17	0.102	50					17*	.715	50	17*	2.4	50	17*	2.5	50				17*	2.48	50	17	.102	200
18	0.102	100					18	.715	100	18	2.4	100	18	2.5	100				18	2.48	100	18	.102	100
19	0.102	200					19	.715	200	19	2.4	200	19	2.5	200				19	2.48	200	19	.102	50
20	0.102	300					20	.715	300	20	2.4	300	20	2.5	300				20	2.48	300			
21	0.204	50					21*	1.01	50	21*	2.4	50	21*	2.9	50				21*	3.0	50			
22	0.204	100					22	1.01	100	22	2.8	100	22	2.9	100				22	3.0	100			
23	0.204	50					23	1.01	200	23	2.8	200	23	2.9	200				23	3.0	200			
							24*	1.36	50	24	2.8	300	24	2.9	300				24	3.0	300			
							25	1.36	100				1	.51	50									

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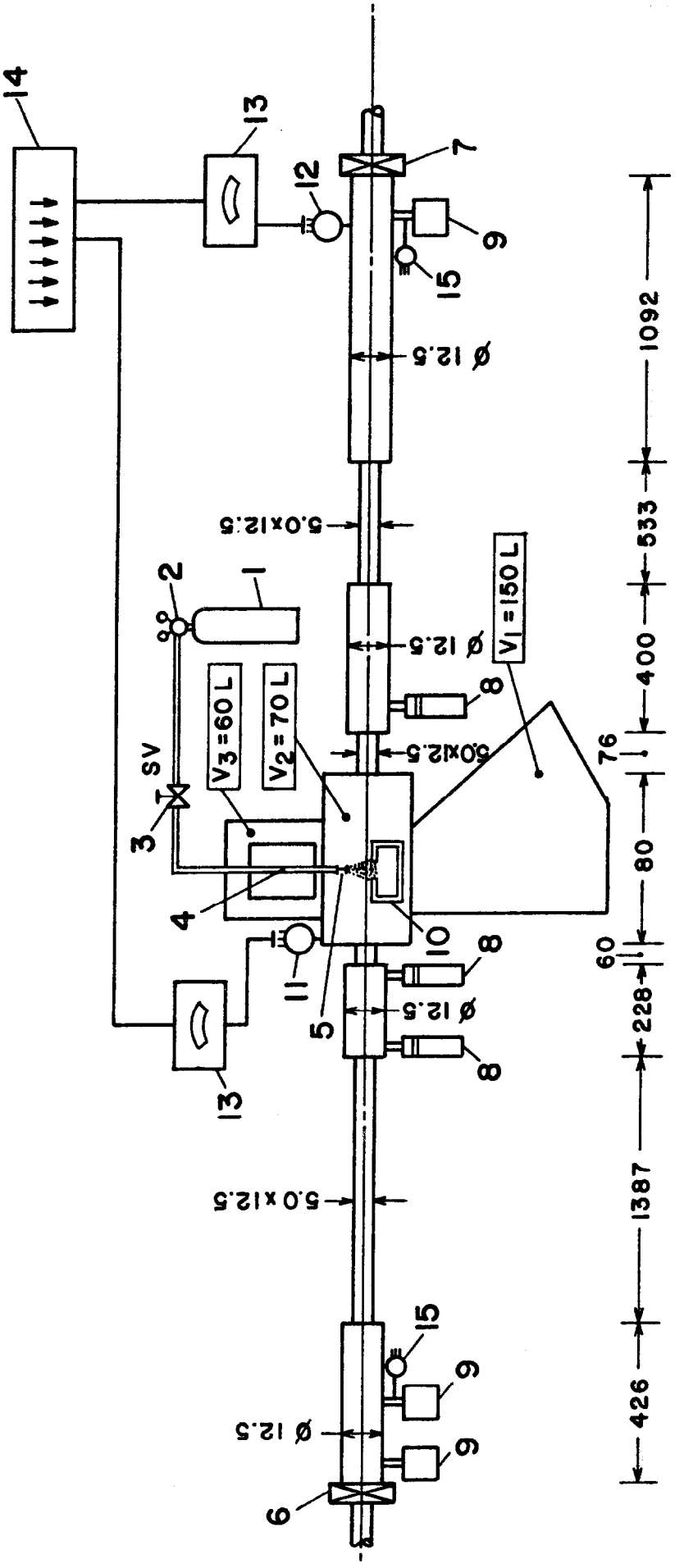
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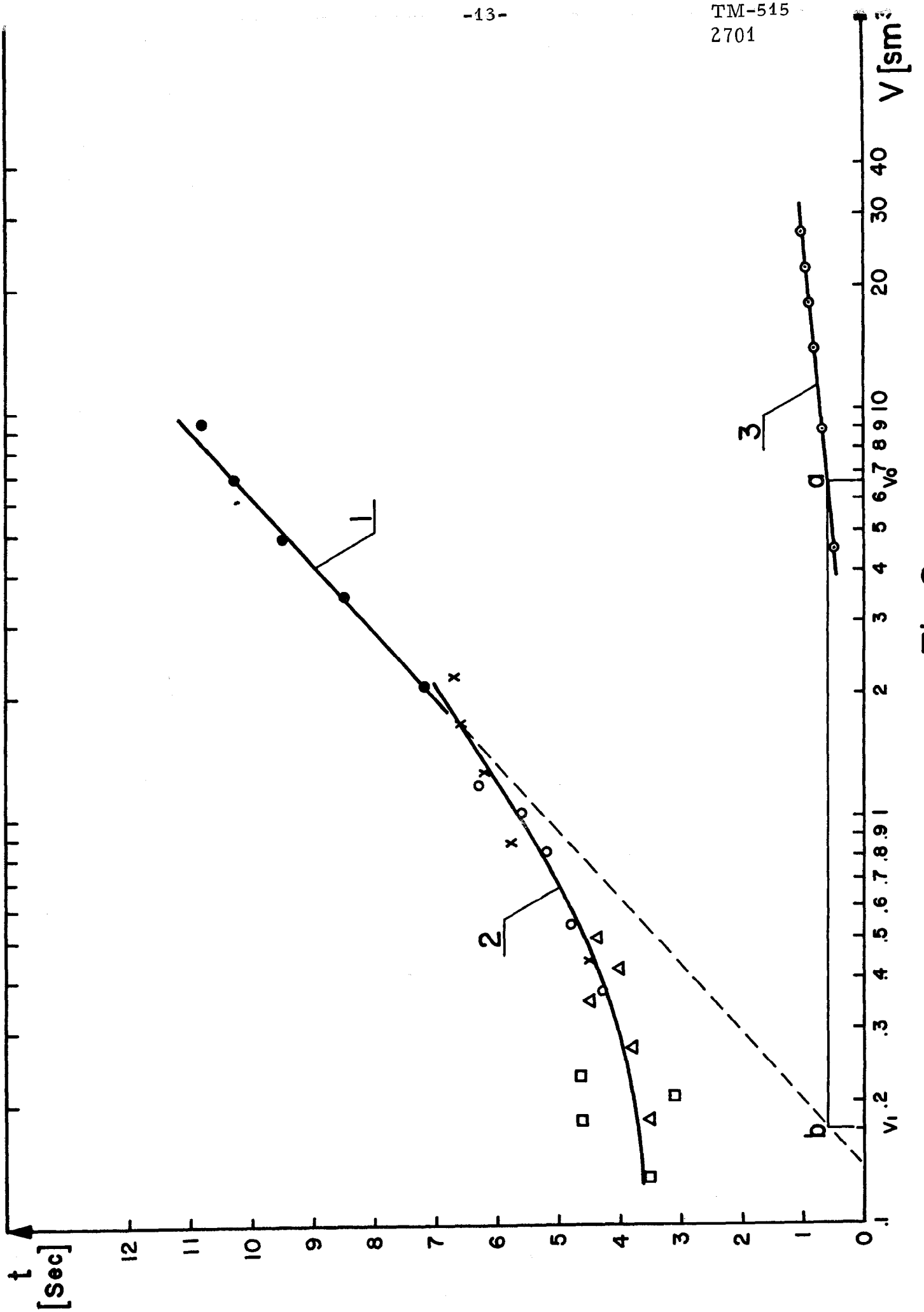
Fig. 1



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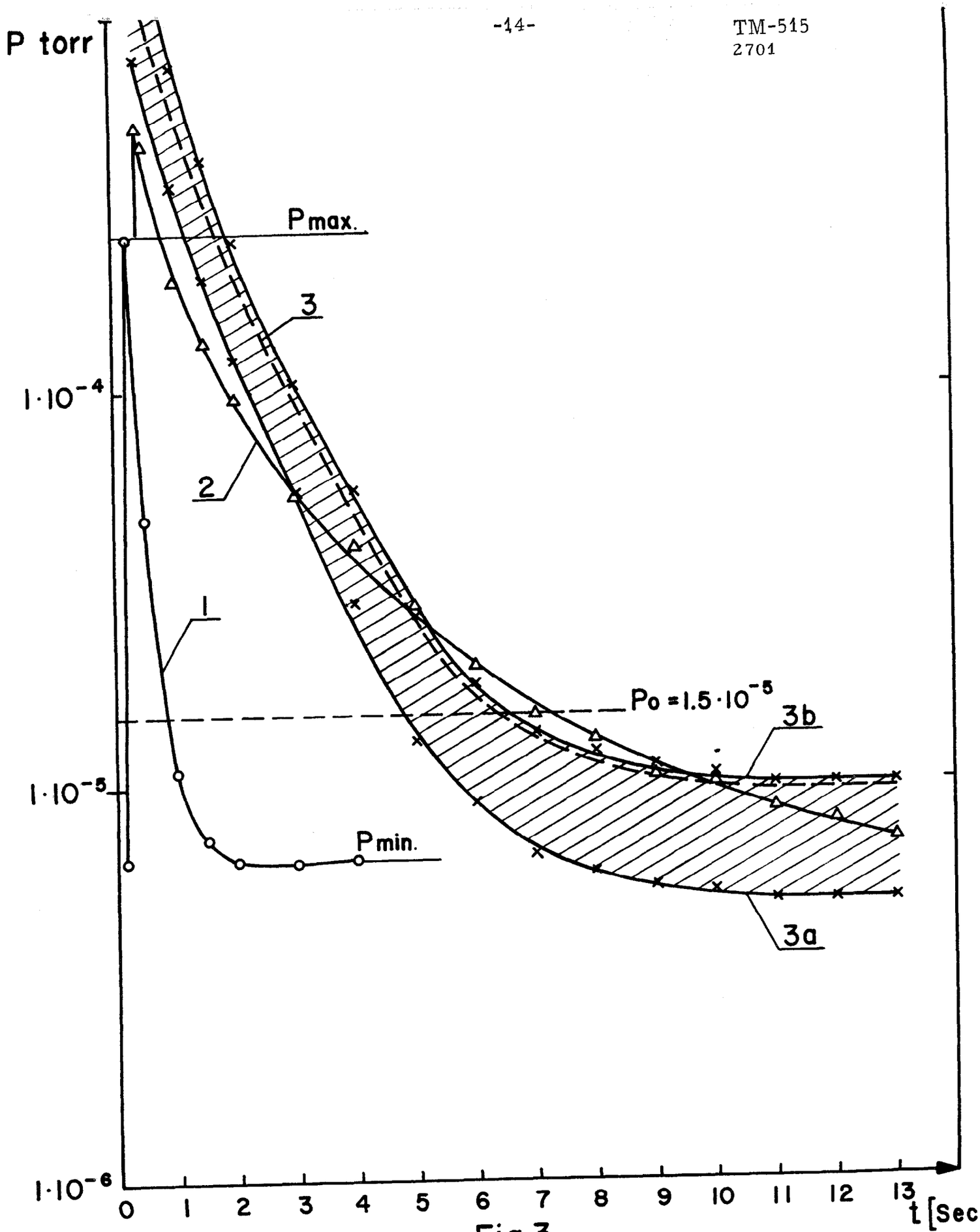
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Fig.3