RESULTS OF THE TESTING OF A TWELVE-INCH BALL VALVE AND A TWELVE-INCH BUTTERFLY VALVE WITH AN ABRUPT ENLARGEMENT SECTION

Prepared for

The Santa Clara County Flood
Control and Water District
San Jose, California

Hydro-Machinery Laboratory
Engineering Research Center
Colorado State University
Fort Collins, Colorado

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by

M. M. Skinner (a)
J. P. Tullis (b)

INTRODUCTION

The use of valves in flow regulating and head breaking structures has grown rapidly over the past several years. A lack of basic information on the hydraulic characteristics of the valves has created numerous problems for the designers of such structures. The information needed for the proper design of the structures falls into three categories. First, information is needed on the head breaking capabilities of the valves (i.e., the relationship of head loss across the valve vs. discharge for various openings). The second area is the mechanical characteristics of the valve involving the torque or thrust exerted on the valve shaft. The third area which must be considered, in order for the structure to operate satisfactorily with a minimum of maintenance, is the cavitation, pressure fluctuation, vibration, and noise characteristics of the individual components and systems.

(a) Assistant Professor, Civil Engineering Department, Colorado State University, Fort Collins, Colorado

(b) Assistant Professor, Civil Engineering Department, Colorado State University, Fort Collins, Colorado

Some structures designed without adequate information on these characteristics have experienced very undesirable operation. Some valves have been destroyed by the erosive effects of cavitation in a period of a few weeks or months.

The third area is extremely important from the standpoint of satisfactory operation of a structure and yet has received little attention by investigators.

OBJECTIVE

In order to optimize the operating characteristics and to extend the life expectancy of pending valve installations, the Santa Clara County Flood Control and Water District initiated a limited laboratory investigation of two twelve-inch valves with a standard downstream enlargement.[c] The objectives were to determine operating conditions that may cause damaging cavitation, to investigate the effectiveness of certain remedial measures for reducing cavitation, and to provide a basis for extrapolating these data to geometrically similar valves of larger size.

(c) Willamette Twelve--Inch Ball Valve, Serial No. 560079, Willamette Iron and Steel Company, Portland, Oregon.
Darling Pelton Twelve-Inch Butterfly Valve, Serial No. 24594-1-1, Darling Valve and Manufacturing Company, Williamsport, Penn.

DESCRIPTION OF TEST LAYOUT

A twelve-inch Willamette Ball Valve and a twelve-inch Darling-Pelton Butterfly Valve were tested in the configurations illustrated in Figure 1 and Figure 2, respectively. One abrupt enlargement configuration was used for both valves. The enlargement consisted of a five-foot length of twenty four-inch pipe with three quarter-inch end plates. A six-inch long section of twelve-inch pipe was used as a short transition between the downstream flange of the valve and the twenty four-inch enlargement. Provision was made for the introduction of air in the sides of the six-inch long transition section and in the shaft of the butterfly valve. A four-inch pipe was tapped into the line upstream from the valve and used in some tests to bypass part of the flow into the enlargement. Ten pressure taps were located at strategic points in the vicinity of the valve and enlargement. A hydrophone was mounted in the upper part of the six-inch transition to record pressure fluctuations. An accelerometer was placed on the downstream flange of the test valve to record either vertical or horizontal acceleration. Four sets of horizontal and vertical velocity traverse ports were located downstream from the enlargement.

Primary discharge measurements were made with an orifice located approximately seventy-five feet upstream from the test valve. In addition, each valve was calibrated in a volumetric test stand at 20, 35, 50, and 70 percent openings for discharges ranging from about

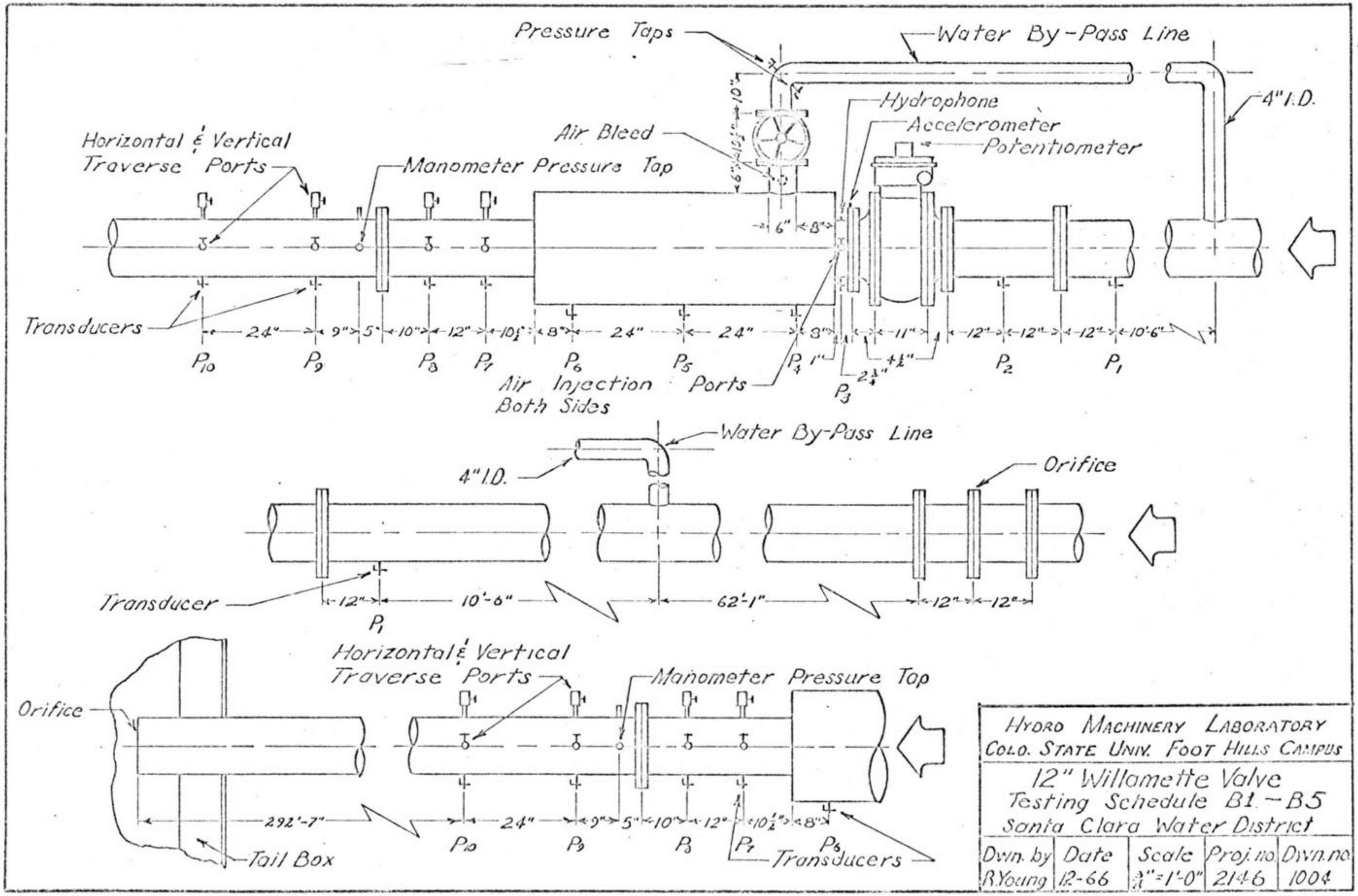

Pressure Taps
Water By-Pass Line
4" I.D.
Hydrophone
Accelerometer
Potentiometer
Air Bleed
Horizontal & Vertical Traverse Ports
Manometer Pressure Tap
Transducers
24"
9"
5"
10"
12"
10½"
8"
24"
24"
8"
1"
2¼"
11"
4½"
12"
12"
12"
10'-6"
6"
8"
P_{10} P_9 P_8 P_7 P_6 P_5 P_4 P_3 P_2 P_1
Air Injection Both Sides
Ports
Water By-Pass Line
4" I.D.
Orifice
Transducer
12"
10'-6"
62'-1"
12"
12"
P_1
Horizontal & Vertical Traverse Ports
Manometer Pressure Tap
Orifice
292'-7"
24"
9"
5"
10"
12"
10½"
8"
P_{10} P_9 P_8 P_7 P_6
Tail Box
Transducers
HYDRO MACHINERY LABORATORY
COLO. STATE UNIV. FOOT HILLS CAMPUS
12" Willamette Valve
Testing Schedule B1 – B5
Santa Clara Water District
Dwn. by R. Young
Date 12-66
Scale 3/8"=1'-0"
Proj. no. 2146
Dwn. no. 1004

Figure 1

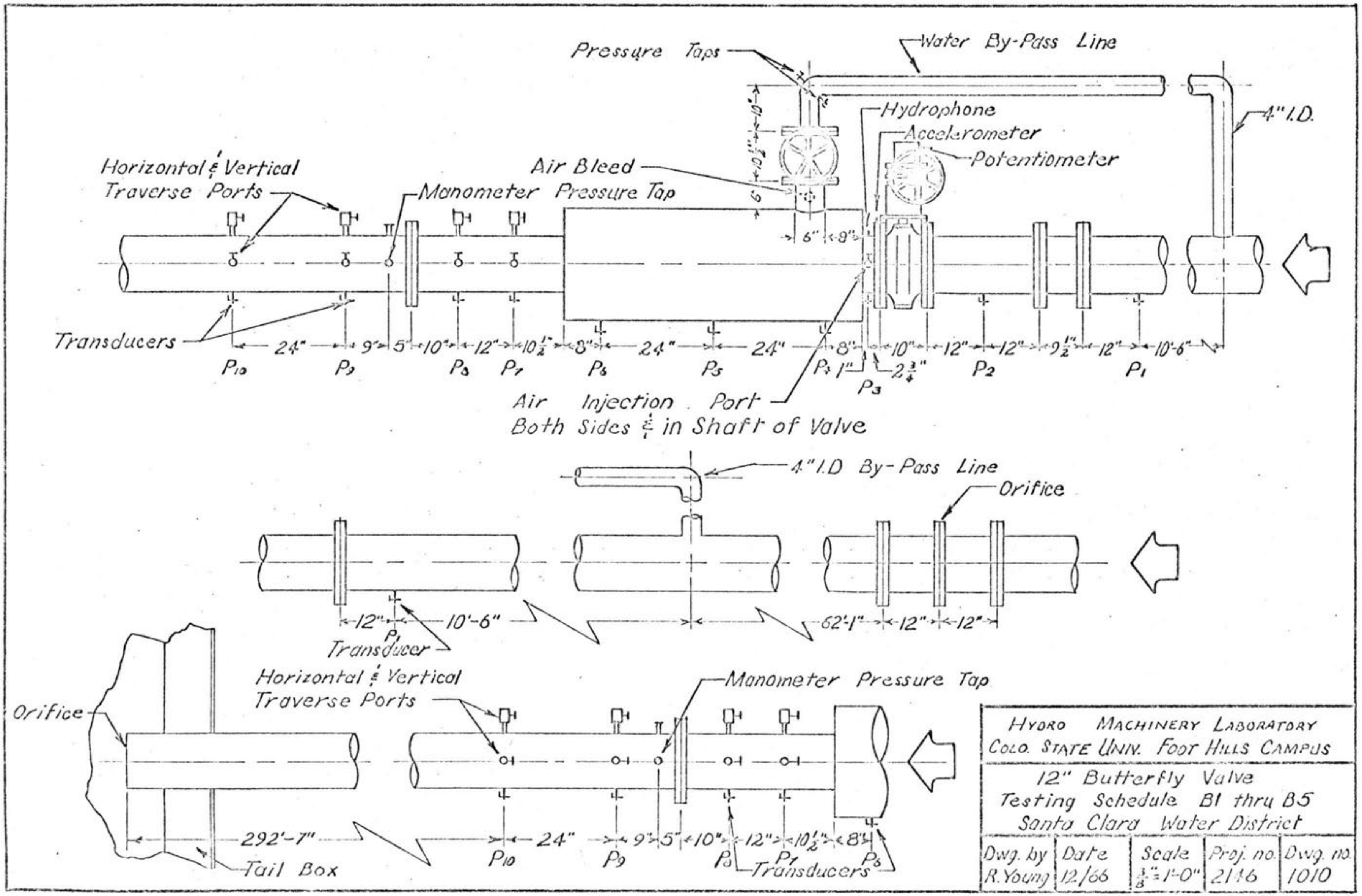

Pressure Taps
Water By-Pass Line
4" I.D.
Hydrophone
Accelerometer
Potentiometer
Air Bleed
Horizontal & Vertical Traverse Ports
Manometer Pressure Tap
Transducers
24" 9" 5" 10" 12" 10½" 8" 24" 24" 8" 1" 10" 12" 12" 9½" 12" 10'-6"
P10 P9 P8 P7 P6 P5 P4 P3 P2 P1
Air Injection Port
Both Sides & in Shaft of Valve
4" I.D By-Pass Line
Orifice
12" 10'-6" 62'-1" 12" 12"
Transducer
Horizontal & Vertical Traverse Ports
Manometer Pressure Tap
Orifice
292'-7" 24" 9" 5" 10" 12" 10½" 8"
Tail Box
Transducers
HYDRO MACHINERY LABORATORY
COLO. STATE UNIV. FOOT HILLS CAMPUS
12" Butterfly Valve
Testing Schedule B1 thru B5
Santa Clara Water District
Dwg. by R. Young
Date 12/66
Scale ⅛" = 1'-0"
Proj. no. 2146
Dwg. no. 1010

Figure 2

one to ten cubic feet per second. The volumetric test stand layout and calibrations are given in Appendix D. The primary discharge measuring orifice was calibrated in the volumetric test stand and also calibrated in place by the "Dye Dilution Method", ("In Situ Calibration of an Orifice by the Dye Dilution Method with Suggested Application to the Rating of Other Types of Meters and Measuring Devices", F. A. Kilpatrick, January 24, 1967, Colorado State University).

The primary indication of the degree of cavitation was obtained from the hydrophone. Pressure transducers were used to record mean pressures and pressure fluctuations. All data were recorded on a tape recorder and selected data were placed on a Visicorder. Pressures, vibration, and hydrophone output were also recorded manually. Hydrophone, transducer and vibration meter information are listed in Appendix F.

TESTING PROCEDURE

All tests were made without pumps in order to minimize the possibility of extraneous noise and pressure fluctuations. The total head, referred to the mid-elevation of the pipeline, ranged from 197 feet of water to 202 feet of water during the ball valve tests and from 204 feet of water to 208 feet of water during the butterfly valve tests. The relatively constant head for any given test sequence was insured by the source of supply "Horsetooth Reservoir" shown in Appendix E - Photograph 1.

Each valve was tested at four different openings: 20, 35, 50 and 70 percent of full rotation. Approximately fifteen runs were made at each opening to define the various stages of cavitation. All tests were recorded on a tape recorder for further analyses of hydrophone output (for selected frequency band widths) vs. Sigma. At test valve openings of 20 and 50 percent, the effect of maximum air injection, water bypass, and a nearby upstream orifice were evaluated. Velocity traverses were performed at selected discharges for the 20 and 50 percent valve openings.

Upstream and downstream pressure heads were measured at taps P_1 and P_{10}, respectively, and corrected for line loss to the test valve flanges. The "sigma" values were used for comparative purpose with test results from recent studies for Bechtel Corporation. The "K" term was used as the index of cavitation for plots in this report. Plots of "K" vs. hydrophone output (volts), "K" vs. valve vibration, and a composite plot of head loss across valve vs discharge for constant downstream head showing cavitating or non-cavitating condition are presented.

The hydrophone output was recorded for three frequency band widths: 2-10 Kc, 4-10 Kc, and 10-200 Kc. Data for all three band widths are provided in the data summary sheets, but only the 10-200 Kc was plotted vs. "K" because the 10-200 Kc band width was found to give a better indication of cavitation.

PARAMETER CALCULATIONS

The parameters that appear on the summary sheets and/or on the various plots are discussed below:

Discharge - expressed in cubic feet per second and measured with a 9-inch calibrated orifice in the 12-inch line

Pressure - measured with pressure transducers and recorded in pounds per square inch; the subscripts, i.e., P_1, P_2; etc., refer to the pressure tap locations illustrated in Figures 1 and 2.

Vibration - obtained from accelerometer readings and given as acceleration in inches per second squared.

Hydrophone output - obtained for three frequency band widths, 2-10 Kc, 4-10 Kc, and 10-200 Kc, and expressed in volts.

Valve opening - amount of shaft rotation expressed as a percentage of full rotation.

Sigma (σ) $= \dfrac{H_d - H_v}{H_u - H_d}$ cavitation index, where H_d = downstream pressure (psi); H_v = vapor pressure of the water relative to atmospheric pressure (-psi); and H_u = upstream pressure (psi). Since the water temperature is relatively constant at the test site the sigma value was calculated by the following equation:

$$\sigma = \frac{H_d + 13}{H_u - H_d}$$

$$K = \frac{H_d - H_v}{H_t - H_d}$$, cavitation index, where

H_d = downstream pressure;

H_v = vapor pressure, relative to the atmosphere (negative value);

H_t = total head upstream (pressure and velocity head).

Dynamic pressure - the pressure fluctuation, in pounds per square inch (peak to peak), at pressure tap P_3, see Figures 1 & 2.

Mean pressure - the average pressure, in pounds per square inch, at pressure tap P_3.

Coefficient of discharge, $C_d = \frac{Q}{A\sqrt{2g\Delta H}}$, where Q is the measured discharge (cfs), A is the area of a 12-inch pipe (.785 ft^2), $g = 32.2\ ft/sec^2$, and ΔH is head loss across valve in feet.

ΔH = difference in pressure head, expressed in feet of water, between upstream and downstream valve flanges.

Incipient critical sigma - the selected value from the sigma vs. hydrophone output curves, where the hydrophone output begins to rise appreciably as the sigma values decrease from conditions of no cavitation.

PLOTTING PROCEDURES

Hydrophone output (volts) vs. K is plotted for various combinations of valve openings and flow conditions. For comparative purposes, the normal flow condition (without air injection, bypass, or orifice 24-inches upstream of the test valve) is plotted on the same sheet for each of the runs involving air injection, bypass or the upstream orifice.

Both horizontal and vertical vibration is recorded in the "data summary sheets", but due to similarity, only the vertical vibrations are plotted vs. K.

The plot of ΔH vs. Q, with lines of constant H_d dividing the cavitating or non-cavitating conditions, was developed by superimposing lines of various levels of H_d on the discharge vs. head loss curves for each valve. The H_d lines represent the limiting operating range for cavitating or non-cavitating conditions described by the incipient cavitation index, Sigma. Since the incipient cavitation value, Sigma, was selected for each valve opening from the test data, the corresponding ΔH may be calculated for the range of downstream pressure heads investigated:*

$$\Delta H = \frac{H_d + 13}{\text{Sigma}}$$

* This calculation involving selected downstream pressure heads is valid only if the system pressure head effect on the incipient cavitation index is non-existent.

Example: A given discharge, downstream pressure head, and head drop specifies a point on the plot; if this point falls on or to the left of the given downstream pressure head line, damaging cavitation should not be encountered.

The selected incipient cavitation values, Sigma, for the two valves at the four openings are given below. It should be noted that these values of Sigma do represent some intermittent bursts of cavitation.

	Incipient Cavitation Values, Sigma	
Valve Opening %	12-inch ball valve	12-inch butterfly valve
20	2.5	2.0
35	2.2	1.8
50	2.8	2.0
70	6.0	2.5

Other important considerations, not illustrated on these operating criteria plots, are the concept of excessive port velocities and the consequent erosive effects on certain type lining materials, excessive vibration, and other phenomenon leading to physical damage to the valve not directly related to cavitation. These various limiting conditions need to be included on design and operating criteria plots. In certain cases these criteria may be more limiting than cavitation damage criteria.

The Q vs. ΔH calibration (volumetric test stand) plots relate the discharge to the change in pressure head (feet of water) between pressure tap locations P_1 and P_3 for both valves. The Q vs. ΔH calibration (in-situ calibration) relates the discharge to the change in pressure head (feet of water) between pressure tap locations P_1 and P_3 and also P_1 and P_{10} for normal operations and with air injection and the orifice 24-inches upstream from the test valve.

DISCUSSION

The hours of operation and total volume of water discharged through each valve are listed below:

12-inch ball valve	95 Hours	85 Acre feet
12-inch butterfly valve	110 Hours	90 Acre feet

The critical sigma (incipient cavitation) values are plotted on Figure 3. The selection of the critical sigma value was based on an arbitrarily selected point on the hydrophone vs. sigma curve where the hydrophone output begins to rise "appreciably" as the sigma value decreases from a condition of no cavitation.

Operation of the valves at sigma values greater than the critical sigma values should insure satisfactory operation from the standpoint of cavitation. Operation at less than the critical sigma values will be accompanied by increased cavitation.

Of the various remedial measures investigated, the air injection had the most beneficial effect. The noise reduction with air injection was especially noticeable when air was injected in the shaft of the Butterfly valve. The air injection rate was about one cubic foot per minute with a compressor pressure of 100 psi. This rate was about the same for all air injection runs for both valves.

Water bypass and the orifice located 24 inches upstream from the test valve had no appreciable effect on critical sigma.

The pressure level effect and size scale effect were not investigated in any phase of the testing on either the 12-inch Willamette or the 12-inch Butterfly Valves. Comparisons were made, however, with data from recent tests for Bechtel Corporation.

Pressure Level Effects:

Due to pump failure, an investigation into the effect of pressure level on the incipient cavitation index, for the two valves studied, was not possible. However, information on pressure scale effects was obtained during testing for the Bechtel Project. As a part of that Project, a considerable amount of testing was done on an eight-inch Willamette Ball Valve, including tests at different heads.

Figures 4 and 5 show the hydrophone output vs sigma curves at head levels between 150 and 350 feet of water for the eight-inch Ball Valve at various valve rotations. On each figure the curves for the higher head are above the curves for the lower head tests, indicating an increase in the pressure fluctuations with increased head.

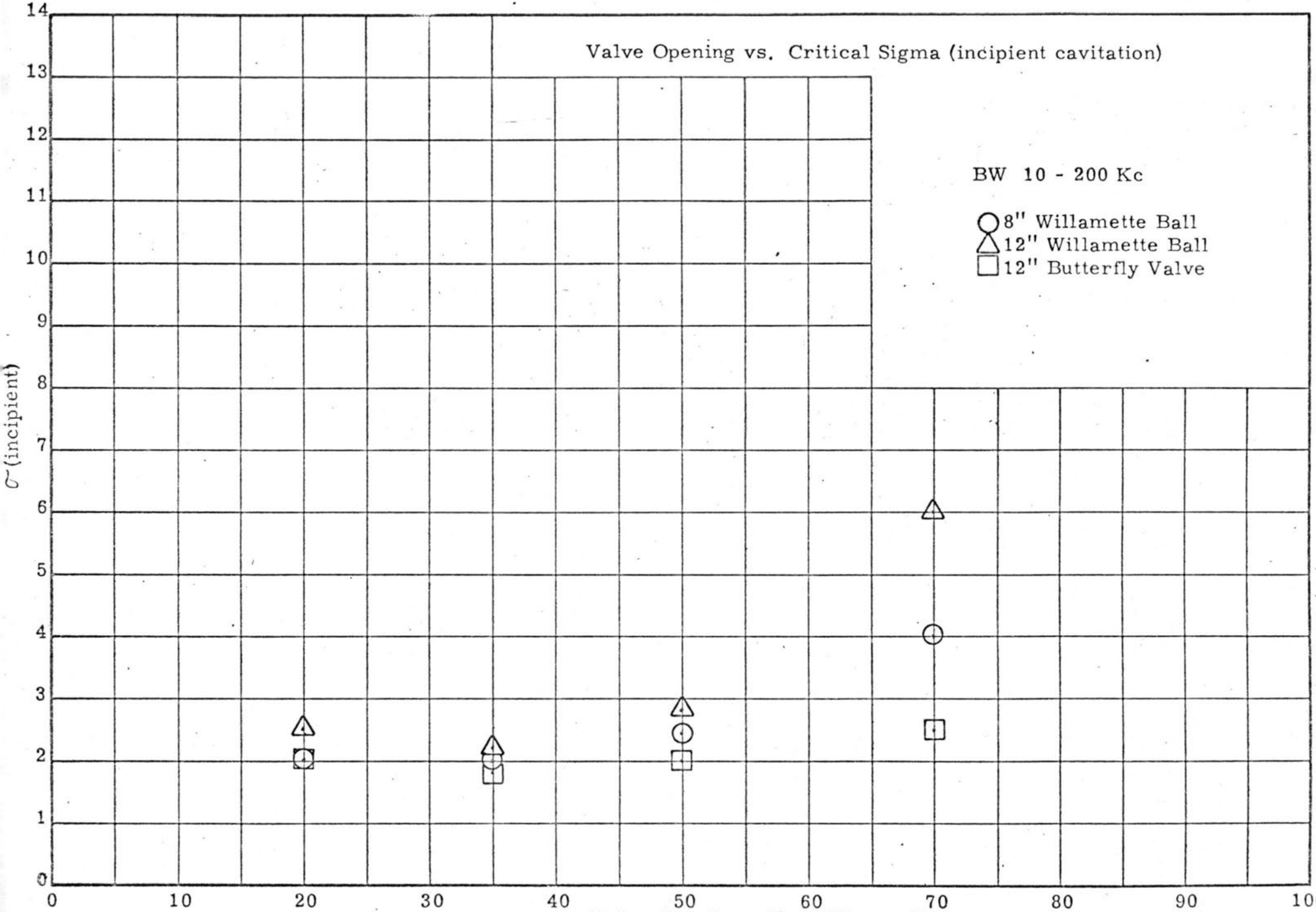

Valve Opening vs. Critical Sigma (incipient cavitation)
BW 10 - 200 Kc
8" Willamette Ball
12" Willamette Ball
12" Butterfly Valve
σ (incipient)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
0
10
20
30
40
50
60
70
80
90
100
Valve Opening - %

Figure 3

This increase in output level could be due, at least in part, to the disturbances generated by the pump impellers.

Another valve tested for the Bechtel Project was a Roto Disc Valve, which is basically a rotating orifice having the shape of a "Horn of Plenty", Figure 6 shows sample results of tests made at two head levels on this valve. Again the curves are offset, but the choice of incipient sigma didn't change.

Two other valves tested (cone and needle) for Bechtel did show a pressure scale effect. For increased heads the incipient cavitation index increased. The existence or absence of a pressure scale effect is apparently related to the geometry and hydraulic characteristics of the individual valves. For a discussion of these factors the Bechtel report should be consulted.

The conclusions regarding the valves tested for this project are: (1) For the Willamette Ball Valve the incipient cavitation index is independent of the operating head, for heads between about 150 and 350 feet of water; (2) There should be little or no pressure scale effect for the Butterfly Valve.

Size Scale Effects:

By comparing the incipient cavitation index for the eight-inch and the 12-inch ball valves,the scale effect due to size can be determined. Figure 3 shows the incipient cavitation index vs. valve rotation for the two sizes of ball valves. It is apparent from the figure that an

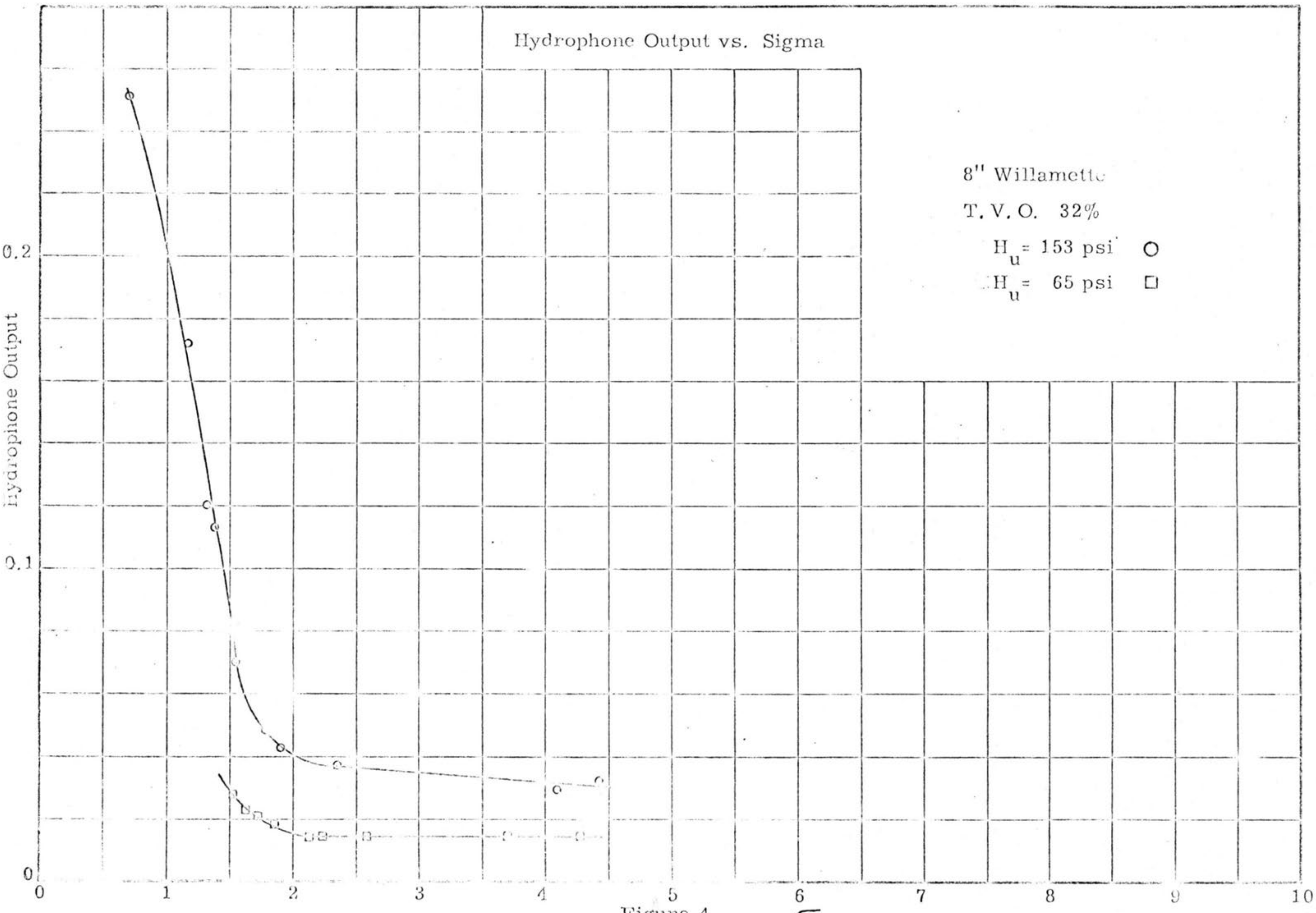
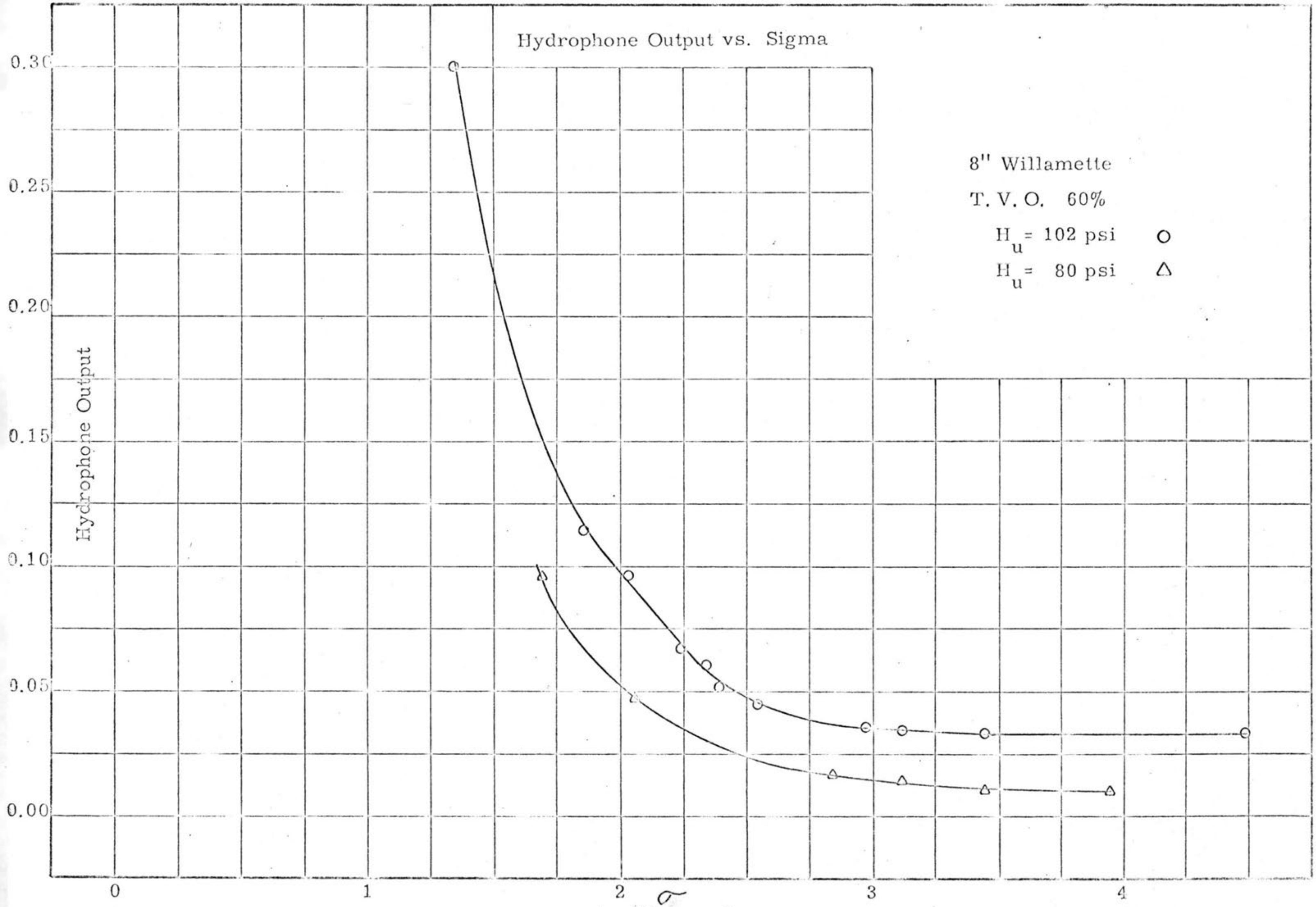

Hydrophone Output vs. Sigma
8" Willamette
T. V. O. 32%
H_u = 153 psi ○
H_u = 65 psi □
Hydrophone Output
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
σ

Figure 4



Hydrophone Output vs. Sigma
8" Willamette
T. V. O. 60%
H_u = 102 psi ○
H_u = 80 psi △
Hydrophone Output
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
σ

Figure 5

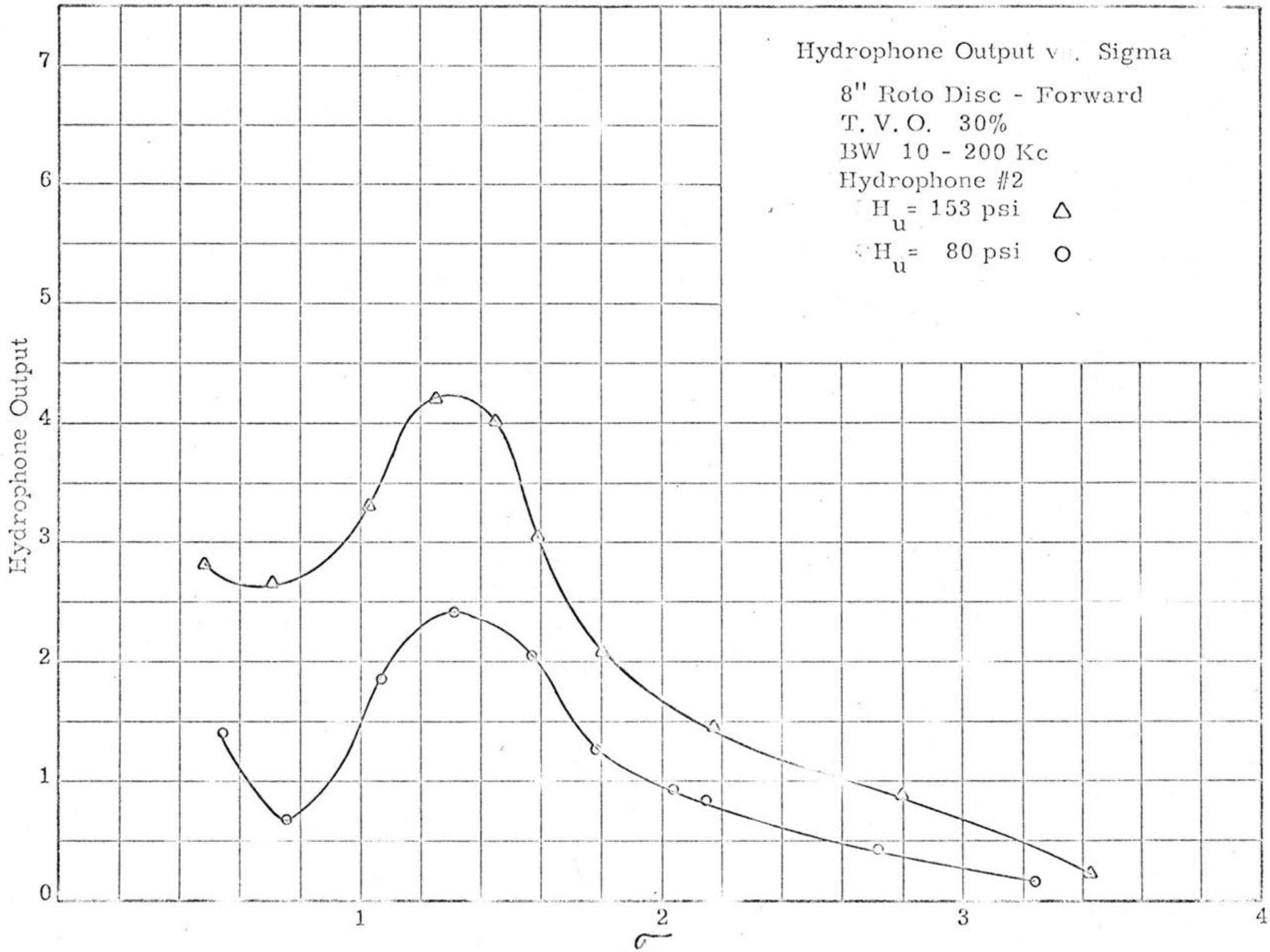

Hydrophone Output vs. Sigma
8" Roto Disc - Forward
T. V. O. 30%
BW 10 - 200 Kc
Hydrophone #2
H_u = 153 psi △
H_u = 80 psi ○
Hydrophone Output
0
1
2
3
4
5
6
7
1
2
3
4
σ

Figure 6

increase in the valve size causes an increase in the value of sigma at incipiency. One factor which makes a direct comparison between the two sizes difficult is that the 12-inch Ball Valve was tested with a sudden expansion downstream, whereas, the 8-inch Ball Valve was tested without an expansion.

CONCLUSIONS AND RECOMMENDATIONS

1. Air injection significantly reduces the value of the incipient cavitation index for both the butterfly and ball valves.
2. Air injected on the right side of the ball valve (looking downstream) is most effective in reducing the cavitation. For the butterfly, equally good results are obtained by injecting air into the stem or on either side of the valve.
3. Bypassing water from upstream of the valve increases the audible noise level and produces no improvement in the incipient cavitation index.
4. Installation of the 6" or 11" orifices 24-inches upstream of the valves does not affect the cavitation characteristics of either valve.
5. The incipient cavitation index for the ball valve is independent of the head; for the range of upstream heads investigated (150-350 feet of water). It is anticipated that the butterfly will likewise have no pressure scale effect.

6. The incipient cavitation index for ball valves increases with increased valve size, (no comparison was available for the butterfly).

7. The values of the incipient cavitation index presented in this report correspond to conditions of light intermittent cavitation (by ear).

8. It is recommended that an investigation to find the value of the cavitation index corresponding to incipient damage be undertaken. The results of this study give information only on the intensity of cavitation. No investigation of cavitation damage was conducted.

Appendix A   Data Summary Sheets

Parameter Summary Sheets

RUN NUMBER CODING SYMBOLS

Example:

Valve type code — Valve rotation of full open (percentage)

12-WB-12-20-1

Size of valve (inches) — Day of month — Run number in a given sequence

Valve type code	Valve type
WB	Willamette Ball Valve
WC	Willamette Ball Valve with 4-inch by-pass wide open.
BF	Darling-Pelton Butterfly Valve
BH	Darling-Pelton Butterfly Valve with 4-inch by-pass wide open.
BG	Darling-Pelton Butterfly Valve--air injection in vented shaft.

CHRONOLOGIC ORDER OF TESTING FOR THE 12" BALL VALVE (WILLAMETTE)

<u>B-1 Testing Schedule</u>

12-WB-12-20-1	through	12-WB-12-20-20
12-WB-13-35-1	"	12-WB-13-35-14
12-WB-13-50-1	"	12-WB-14-50-16
12-WB-14-70-1	"	12-WB-15-70-16

<u>B-3 Testing Schedule</u> (5% of total discharge in by-pass)

12-WB-20-20-1	through	12-WB-21-20-13
12-WB-22-20-1	"	12-WB-22-20-7

<u>B-3 Testing Schedule</u> (by-pass wide open)

12-WC-21-20-1	through	12-WC-22-20-15

<u>B-4 Testing Schedule</u> (11-inch orifice 24-inches upstream from 12-inch Ball Valve)

12-WB-27-20-1	through	12-WB-28-20-17
12-WB-28-50-1	"	12-WB-28-50-8

<u>B-2 Testing Schedule</u> (air injection in right or left side of 6-inch transition section)

12-WB-28-50-5L	through	12-WB-28-50-8L
12-WB-13-20-1	"	12-WB-13-20-5
12-WB-13-50-1	"	12-WB-13-50-5

CHRONOLOGIC ORDER OF TESTING FOR THE
12" BUTTERFLY VALVE (DARLING PELTON)

B-3 Testing Schedule (by-pass wide open)

12-BH-29-20-1 through 12-BH-30-20-11

B-2 Testing Schedule (air injection in vented shaft)

12-BG-29-20-1 through 12-BG-4-20-20

B-1 & B-2 Testing Schedule (no air injection or air injection in right or left side of 6-inch transition section)

12-BF-29-20-1 through 12-BF-4-20-19

B-1 Testing Schedule

12-BF-5-35-1 through 12-BF-6-35-15

B-1 & B-2 Testing Schedule (no air injection or air injection in right or left side of 6-inch transition section)

12-BF-6-50-1 through 12-BF-9-50-11

B-2 Testing Schedule (air injection in vented shaft)

12-BG-6-50-1 through 12-BG-9-50-10

B-3 Testing Schedule (by-pass wide open)

12-BH-6-50-1 through 12-BH-9-50-7

B-1 Testing Schedule

12-BF-9-70-1 through 12-BF-9-70-9

(Testing for 12" Butterfly Valve cont'd)

B-4 Testing Schedule

12-BF-10-20-1	through	12-BF-10-20-11
12-BF-11-50-7	"	12-BF-11-50-16

DATA SUMMARY SHEET

Run No.	Discharge (cfs)	Pressure (pounds per square inch)										Vert. Vib. (IPS)	Horiz. Vib. (IPS)	Hydrophone (volts)		
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}			10-200 Kc	4-10 Kc	2-10 Kc
12-WB-12-20-1	7.10	79.0	78.9	44.8	44.0	46.6	46.9	46.0	46.2	45.9	46.0	25,000	28,000	4.80	2.60	4.20
-2	6.44	79.8	79.6	49.7	48.8	51.3	51.7	50.8	50.8	50.6	50.8	24,000	19,500	2.60	1.88	3.00
-3	6.24	80.1	80.0	52.3	51.7	53.7	54.1	53.2	53.4	53.2	53.3	22,000	20,500	1.72	1.40	2.20
-4	6.03	80.4	80.3	54.1	53.5	55.5	55.8	55.2	55.3	54.8	55.1	2,400	12,500	1.28	1.12	1.76
-5	5.78	80.9	80.6	56.3	55.5	57.6	58.0	57.2	57.3	57.1	57.3	25,000	14,500	0.68	0.84	1.35
-6	5.64	81.0	80.9	58.3	57.4	59.3	60.0	59.2	59.2	59.1	59.3	13,000	9,000	0.44	0.60	1.05
-7	5.40	81.2	81.5	60.3	59.6	61.0	61.8	60.9	61.0	61.0	61.0	12,000	6,000	0.36	0.46	0.62
-8	5.32	81.3	81.7	61.7	61.2	62.5	63.1	62.6	62.6	62.5	62.1	7,000	7,500	0.28	0.39	0.52
-9	5.02	81.4	81.7	62.6	62.0	63.2	64.0	63.4	63.5	63.3	63.2	7,000	5,000	0.255	0.31	0.43
-10	4.86	81.8	81.9	64.9	64.0	65.5	66.5	66.2	66.1	66.0	65.9	2,000	1,800	0.16	0.18	0.21
-11	4.48	82.4	82.4	67.8	67.7	68.6	68.8	69.0	68.7	68.3	68.5	750	340	0.10	0.10	0.10
-12	5.56	81.0	80.9	59.0	58.8	60.7	60.6	60.4	60.2	59.8	60.4	11,000	3,000	0.40	0.60	0.78
-13	7.22	78.2	78.0	41.6	40.2	43.8	44.0	43.4	43.2	47.9	43.4	30,000	30,000	4.52	3.12	4.68
-14	7.69	77.6	77.7	35.0	34.0	37.9	38.5	37.4	37.2	36.9	37.5	30,000	30,000	7.12	3.64	5.48
-15	8.36	76.3	76.2	26.3	24.5	29.4	30.2	28.9	29.0	28.9	29.0	30,000	30,000	9.40	4.32	6.60
-16	8.86	74.8	75.0	17.8	15.3	20.9	20.9	20.1	20.2	20.1	20.2	30,000	30,000	8.12	5.48	8.20
-17	9.20	74.4	74.3	9.8	8.4	14.2	14.8	13.7	13.9	13.7	13.9	30,000	30,000	8.00	7.80	11.12
-18	9.06	74.8	74.8	14.9	11.8	17.8	17.5	16.8	17.0	16.6	17.0	30,000	30,000	8.12	6.52	9.28
-19	9.36	74.0	73.8	6.8	5.4	10.8	11.2	9.9	10.1	9.9	10.0	30,000	30,000	8.20	9.60	14.00
-20	9.44	73.6	73.8	3.0	2.3	7.8	8.2	6.5	6.6	6.7	6.6	30,000	30,000	9.00	12.00	16.80
12-WB-13-35-1	13.30	63.8	64.0	29.1	24.6	30.4	30.6	27.9	28.1	28.0	28.0	35,000	30,000	6.16	3.12	4.8
-2	12.81	65.3	65.7	32.8	29.3	33.8	34.5	31.8	32.2	32.0	32.0	30,000	20,000	4.52	2.76	4.28
-3	14.02	61.4	61.7	23.6	18.6	24.8	25.0	21.8	21.9	21.5	21.5	30,000	35,000	7.8	3.68	5.52
-4	14.79	58.9	59.3	17.6	11.4	18.8	18.4	15.0	15.2	15.1	15.0	45,000	60,000	7.72	5.28	7.44
-5	12.12	67.1	67.4	39.0	33.8	39.0	39.5	37.3	37.3	37.1	37.2	20,000	24,000	2.8	2.24	3.48
-6	11.81	68.2	68.6	41.9	37.1	41.8	42.3	40.1	40.2	39.7	40.1	18,000	20,000	1.96	1.76	2.76
-7	11.46	69.1	69.6	44.2	39.6	44.1	44.5	42.4	42.6	42.3	42.5	16,000	16,000	1.40	1.40	2.01

DATA SUMMARY SHEET

Run No.	Discharge (cfs)	Pressure (pounds per square inch)										Vert. Vib. (IPS)	Horiz. Vib. (IPS)	Hydrophone (volts)		
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}			10-200 Kc	4-10 Kc	2-10 Kc
12-WB-13-35-8	10.70	71.1	71.8	49.3	45.0	49.1	49.6	47.9	47.8	47.6	47.7	12,000	10,000	0.64	0.688	1.08
-9	10.49	71.6	72.2	50.7	46.3	50.3	50.9	49.2	49.2	49.0	49.3	8,000	8,000	0.528	0.608	0.908
-10	10.25	72.3	72.8	52.6	48.5	52.1	52.8	51.1	51.2	50.8	51.2	5,500	5,500	0.392	0.460	0.68
-11	9.94	73.2	73.5	54.3	51.3	53.6	54.6	53.1	53.4	53.3	53.1	5,000	4,500	0.32	0.38	0.56
-12	8.82	75.7	76.0	60.9	58.1	60.2	61.4	60.2	60.3	59.6	59.9	650	600	0.14	0.125	0.21
-13	9.31	73.0	73.3	53.9	50.5	53.4	54.8	53.2	53.5	52.5	53.1	4,500	5,000	0.30	0.340	0.540
-14	8.82	74.4	74.6	56.4	54.4	56.6	57.7	56.4	56.4	56.3	56.3	3,500	4,000	0.256	0.220	0.332
12-WB-13-50-1	15.999	52.4	52.4	33.4	27.3	33.6	33.6	29.9	30.2	29.4	29.7	14,000	20,000	2.56	1.80	3.04
-2	15.281	55.2	54.8	37.6	31.7	37.6	37.6	34.0	34.4	34.1	33.8	15,000	20,500	1.56	1.24	2.36
-3	14.819	56.6	56.5	39.6	34.4	39.6	40.0	36.6	36.7	36.6	36.4	13,000	16,000	1.12	1.00	2.00
-4	14.563	57.0	57.0	39.3	35.4	40.0	40.4	36.8	37.3	37.4	36.8	13,000	9,000	1.12	0.980	1.92
-5	14.214	58.5	58.5	42.0	37.7	41.9	42.6	39.2	39.5	39.8	39.3	9,000	11,000	0.860	0.820	1.64
-6	13.599	60.1	60.1	44.8	40.8	44.8	45.2	42.0	42.4	42.6	42.1	9,000	11,000	0.628	0.62	1.36
-7	12.666	62.4	62.4	48.4	45.3	48.8	49.2	46.4	46.8	45.9	46.2	6,500	8,000	0.40	0.492	0.948
-8	12.235	63.8	63.8	50.6	47.7	51.0	51.4	48.8	48.8	48.0	48.6	5,000	6,000	0.380	0.388	0.780
-9	11.855	65.2	65.2	53.3	50.3	52.1	53.2	50.8	50.9	51.7	50.6	5,500	6,000	0.296	0.304	0.64
-10	10.871	68.0	68.0	57.3	55.0	57.7	58.0	55.9	56.1	55.6	55.7	1,800	2,000	0.128	0.176	0.340
-11	10.307	69.8	69.8	60.3	58.1	60.4	60.9	58.8	59.3	59.7	58.8	400	500	0.072	0.104	0.260
-12	9.845	71.4	71.4	62.5	60.7	62.6	63.2	61.4	61.8	62.2	61.4	300	400	0.060	0.08	0.20
-13	8.912	73.6	73.6	66.2	64.7	66.3	66.8	65.4	65.8	66.6	65.4	80	50	0.064	0.052	0.136
-14	8.348	75.6	75.6	69.7	68.2	69.1	69.7	68.6	68.4	69.2	68.4	60	50	0.096	0.044	0.096
-15	11.332	66.2	66.2	54.7	52.6	54.8	55.2	53.0	53.4	52.7	53.0	4,000	5,000	0.216	0.240	0.50
12-WB-14-50-16	12.59	22.8	22.4	11.2	4.8	10.9	10.7	8.6	9.1	8.9	8.9	9,000	12,000	--	--	--
12-WB-14-70-1	18.02	46.7	46.3	40.4	33.9	39.0	40.4	35.4	35.7	35.8	35.4	12,000	9,000	0.78	0.90	1.6
-2	17.69	48.2	47.8	42.0	35.7	40.6	41.9	37.2	37.8	38.0	37.3	12,000	10,000	0.67	0.80	1.45

DATA SUMMARY SHEET

Run No.	Discharge (cfs)	Pressure (pounds per square inch)										Vert. Vib. (IPS)	Horiz. Vib. (IPS)	Hydrophone (volts)		
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}			10-200 Kc	4-10 Kc	2-10 Kc
12-WB-14-70-3	17.28	49.7	49.4	43.6	37.8	42.6	43.8	39.5	39.7	40.0	39.3	7,000	8,500	0.48	0.62	0.95
-4	16.68	52.6	52.7	47.3	42.7	45.9	47.1	43.3	43.4	43.1	43.2	6,500	7,500	0.30	0.40	0.62
-5	16.11	54.3	54.4	49.3	45.1	48.0	49.1	45.7	45.7	45.3	45.3	8,500	7,000	0.18	0.22	0.50
-6	14.72	59.2	59.5	55.1	51.3	53.8	55.0	51.9	51.9	51.5	51.9	2,000	2,100	0.07	0.06	0.12
12-WB-15-70-7	14.46	60.4	60.4	56.3	55.1	55.4	56.5	53.3	53.4	53.0	53.1	2,000	2,100	0.07	0.10	0.14
-8	13.92	62.3	62.2	58.4	57.5	57.4	58.7	55.8	56.3	55.6	55.7	170	200	0.032	0.05	0.08
-9	13.28	64.6	64.3	61.5	59.8	60.0	61.2	58.3	58.9	58.4	58.6	55	45	0.024	0.022	0.043
-10	16.42	53.2	53.0	47.6	46.3	46.1	47.4	43.5	44.1	43.2	43.5	5,000	4,500	0.42	0.52	0.80
-11	16.11	54.9	54.8	50.1	48.5	48.4	49.6	46.1	46.2	46.0	45.8	5,000	4,000	0.24	0.32	0.60
-12	16.16	54.4	54.5	49.6	48.3	47.9	48.7	45.7	45.5	45.1	45.2	4,500	5,000	0.24	0.35	0.60
-13	15.72	56.6	56.4	51.4	50.1	50.0	51.1	47.7	47.7	47.5	47.7	4,700	3,500	0.16	0.25	0.37
-14	15.11	58.4	58.5	54.3	52.8	52.6	53.5	50.6	50.5	50.3	50.4	2,000	1,800	0.075	0.12	0.17
-15	17.55	48.6	48.7	42.5	40.6	41.1	42.5	37.9	38.3	37.9	38.1	7,500	5,500	0.73	0.85	1.50
-16	17.32	49.7	49.8	43.7	42.2	42.8	44.0	38.9	39.6	39.4	39.0	7,000	6,500	0.52	0.67	1.20
12-WB-21-20-1	9.845	74.8	74.7	7.6	10.8	11.8	12.7	10.9	10.6	10.8	10.6	50,000	60,000	8.20	7.80	10.80
-2	9.486	75.2	75.1	11.8	14.8	15.7	15.9	14.5	14.7	15.0	14.6	50,000	40,000	7.92	7.20	9.60
-3	9.332	76.1	76.1	18.4	21.7	22.9	23.0	21.5	21.4	21.7	21.7	55,000	35,000	9.00	5.20	7.40
-4	8.871	76.6	76.2	24.0	26.9	27.6	27.8	26.4	26.5	26.5	26.6	45,000	40,000	9.72	4.60	6.96
-5	8.707	77.0	76.4	28.3	30.4	30.9	31.6	30.3	30.3	30.2	30.4	39,000	28,000	9.36	4.24	6.40
-6	8.307	77.8	77.3	34.0	36.6	37.4	36.2	36.2	36.1	36.3	36.3	35,000	19,000	7.60	3.68	5.68
-7	7.486	79.1	78.8	43.4	44.9	45.7	46.0	44.8	44.7	44.7	45.1	34,000	16,000	3.96	2.80	4.40
-8	7.086	79.7	79.1	47.9	49.3	49.9	50.0	49.2	49.1	49.1	49.4	26,000	23,000	2.22	2.28	3.40
-9	6.584	80.2	79.9	51.8	52.8	53.6	53.7	52.9	52.9	53.0	53.2	30,000	20,000	1.33	1.53	2.35
-10	5.610	82.6	82.6	62.4	63.2	63.2	63.6	62.9	63.2	62.7	63.3	5,000	4,000	0.18	0.43	0.56
-11	5.579	82.5	82.9	63.2	63.8	64.1	64.7	64.1	63.8	64.2	64.2	5,000	4,000	0.235	0.40	0.50
-12	4.635	83.8	84.2	70.5	70.9	70.8	71.1	71.0	71.1	70.5	71.1	240	150	0.088	0.06	0.07

DATA SUMMARY SHEET

Run No.	Discharge (cfs)	Pressure (pounds per square inch)										Vert. Vib. (IPS)	Horiz. Vib. (IPS)	Hydrophone (volts)		
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}			10-200 Kc	4-10 Kc	2-10 Kc
12-WB-21-20-13	3.671	84.8	84.9	75.3	75.4	75.7	76.0	75.6	75.7	75.9	75.8	50	70	0.025	0.01	0.022
12-WB-22-20-1	6.58	80.7	81.0	53.8	54.8	55.6	55.5	54.6	54.5	54.8	55.2	24,000	10,000	1.0	1.76	1.95
-2	6.23	81.1	81.3	56.6	57.5	58.2	58.1	57.3	57.2	57.4	57.8	16,000	8,000	0.62	0.95	1.25
-3	6.32	82.1	81.7	56.0	57.3	57.4	57.6	57.2	57.3	56.4	57.2	13,130	6,000	0.75	0.95	1.53
-4	5.78	82.8	82.1	60.7	61.6	61.8	62.2	61.6	61.7	61.0	61.8	7,500	6,000	0.34	0.57	0.80
-5	9.11	76.8	76.4	20.0	21.3	22.9	22.9	21.0	22.2	21.7	22.0	45,000	12,000	9.04	5.32	7.84
-6	9.53	75.8	75.2	11.8	14.8	15.1	15.9	14.4	15.0	14.6	14.4	55,000	50,000	7.80	7.28	10.40
-7	9.67	75.2	75.0	7.8	10.8	11.7	12.0	10.3	10.6	10.6	10.6	40,000	36,000	8.08	9.40	13.60
12-WC-21-20-1	6.061	82.3	82.4	70.4	70.2	70.8	71.2	70.4	70.2	70.5	70.7	200	180	0.04	0.035	0.055
-2	9.066	82.2	82.4	71.0	71.1	71.5	71.8	71.2	71.0	71.4	71.3	140	100	0.06	0.027	0.047
-3	4.789	83.5	83.7	76.3	76.3	76.5	76.8	76.5	76.2	76.7	76.6	70	40	0.015	0.005	0.005
12-WC-22-20-4	6.707	80.3	80.5	65.6	65.9	66.4	66.4	65.5	65.3	66.2	66.0	2,000	1,000	0.12	0.11	0.12
-5	6.92	81.4	81.1	65.2	66.1	66.2	66.4	65.7	65.9	65.1	65.7	800	700	0.15	0.13	0.16
-6	6.24	82.7	82.1	69.6	69.6	69.9	70.1	69.9	69.7	69.8	70.0	220	200	0.08	0.049	0.052
-7	11.23	72.9	72.4	31.8	32.1	33.4	33.4	31.9	32.0	31.6	31.8	39,000	26,000	7.64	3.48	5.36
-8	10.70	74.5	73.8	37.6	37.6	38.6	38.8	37.4	37.5	37.1	37.3	30,000	20,000	5.48	3.00	4.80
-9	10.25	75.8	75.1	42.3	42.4	43.4	43.3	42.1	42.3	41.8	41.9	30,000	25,000	3.60	2.56	4.04
-10	9.68	76.7	76.2	46.6	46.6	47.6	47.6	46.5	46.6	45.9	46.5	30,000	23,000	2.52	2.00	3.20
-11	8.66	77.9	77.4	53.4	54.4	54.7	55.3	53.7	54.1	53.7	53.9	14,000	12,000	0.71	0.95	1.45
-12	7.86	79.3	78.9	58.8	59.6	59.8	60.3	59.2	59.4	59.2	59.3	6,000	5,000	0.30	0.45	0.63
-13	7.28	80.3	79.9	63.1	63.9	63.7	64.3	63.2	63.5	63.2	63.4	2,000	1,700	0.17	0.21	0.26
-14	12.06	70.1	69.6	22.7	24.0	24.9	25.2	22.6	23.1	23.3	22.8	36,000	35,000	8.60	4.08	6.20
-15	12.25	68.8	68.6	16.6	18.6	19.4	19.8	17.2	17.7	17.7	17.2	50,000	26,000	7.48	4.80	7.08
12-WB-27-20-1	9.40	78.7	76.3	8.1	11.4	13.1	12.3	12.2	11.9	11.3	11.7	60,000	45,000	8.40	9.68	14.40
-2	9.27	76.3	75.5	11.5	14.1	14.7	15.2	13.9	14.4	14.4	14.1	60,000	45,000	7.72	7.60	10.80

DATA SUMMARY SHEET

Run No.	Discharge (cfs)	Pressure (pounds per square inch)										Vert. Vib. (IPS)	Horiz. Vib. (IPS)	Hydrophone (volts)		
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}			10-200 Kc	4-10 Kc	2-10 Kc
12-WB-27-20-3	8.96	77.4	77.4	19.0	21.6	22.8	22.9	21.5	22.2	21.4	20.7	45,000	30,000	8.60	5.32	8.00
-4	8.74	78.8	78.8	22.8	25.6	26.4	27.4	26.3	26.0	26.0	25.8	50,000	30,000	--	4.72	7.08
-5	8.29	79.0	77.5	27.2	29.2	30.0	30.5	29.2	29.8	29.8	29.4	45,000	28,000	9.52	4.16	6.28
-6	8.03	81.2	79.0	35.2	37.5	37.7	38.2	37.7	37.6	37.8	37.2	40,000	25,000	7.68	3.64	5.48
-7	7.41	80.4	80.4	41.9	43.7	44.2	44.3	42.9	43.5	43.7	43.0	35,000	22,000	5.00	3.04	4.64
-8	6.94	82.6	81.6	48.2	50.0	50.0	50.6	49.7	50.2	50.2	49.6	26,000	14,000	2.80	2.16	3.36
-9	6.53	82.6	80.9	52.2	53.1	53.5	54.0	52.7	53.7	53.6	53.4	24,000	12,000	1.80	1.56	2.52
12-WB-28-20-10	7.42	81.2	81.2	42.4	43.8	44.5	44.8	43.2	43.8	44.1	43.6	40,000	20,000	5.08	3.12	4.72
-11	7.16	81.6	81.6	45.4	46.8	47.5	47.7	46.5	46.8	47.2	46.7	35,000	22,000	3.92	2.72	3.88
-12	6.06	83.3	83.7	57.9	58.4	58.8	58.9	58.2	58.2	58.6	58.2	22,000	16,000	0.74	0.90	1.45
-13	6.84	81.9	81.4	48.8	50.2	50.3	50.7	50.0	50.0	50.6	50.1	28,000	20,000	2.72	2.20	3.32
-14	5.48	84.0	83.5	62.0	63.2	63.2	63.8	63.0	63.0	63.7	63.2	8,500	8,000	0.23	0.43	0.54
-15	4.92	84.5	84.3	67.2	68.0	68.0	68.3	67.7	68.2	68.3	67.9	2,000	1,600	0.135	0.145	0.18
-16	4.54	85.0	84.8	70.0	70.7	70.7	71.0	70.6	71.1	71.0	70.9	500	450	0.085	0.06	0.07
-17	4.24	85.3	85.3	72.2	72.8	72.8	73.0	72.6	73.1	72.9	72.9	200	180	0.06	0.03	0.045
12-WB-28-50-1	9.89	75.3	74.7	67.8	67.8	68.1	68.3	67.0	66.9	66.4	66.9	85	40	0.046	0.069	0.173
-2	12.12	69.5	68.9	58.2	58.4	58.3	58.4	56.4	56.7	56.4	56.2	4,000	2,000	0.156	0.208	0.42
-3	11.54	71.6	70.8	61.1	60.7	60.7	61.5	59.3	59.7	60.2	59.3	1,800	1,000	0.112	0.148	0.304
-4	10.72	74.0	73.1	64.6	64.4	64.1	64.8	62.9	63.2	63.7	62.9	450	400	0.052	0.096	0.224
-5	13.90	64.4	62.8	48.5	48.4	48.7	49.1	46.2	46.6	46.3	46.1	8,500	8,000	0.420	0.50	1.0
-6	12.86	67.5	66.6	54.6	54.2	54.5	54.8	52.2	53.1	53.1	52.4	6,000	4,000	0.252	0.288	0.60
-7	15.48	58.4	57.4	40.4	40.0	40.0	40.8	37.1	37.5	37.9	37.1	16,000	14,000	1.16	1.04	2.00
-8	16.55	54.2	53.2	33.4	33.0	32.9	33.8	29.6	30.0	29.8	29.7	20,000	16,000	2.80	1.84	3.12
12-WB-28-50-5L	13.90	64.4	63.0	48.9	48.6	48.6	49.2	46.2	46.6	46.3	46.1	--	--	0.500	0.480	0.96
-5R	13.90	63.9	63.0	48.9	48.7	48.5	49.2	46.2	46.4	46.2	46.1	--	--	0.400	0.420	0.84
-6R	12.86	67.5	66.7	54.6	54.2	54.0	54.9	52.2	52.9	53.1	52.4	--	--	0.368	0.260	0.56

DATA SUMMARY SHEET

Run No.	Discharge (cfs)	Pressure (pounds per square inch)										Vert. Vib. (IPS)	Horiz. Vib. (IPS)	Hydrophone (volts)		
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}			10-200 Kc	4-10 Kc	2-10 Kc
12-WB-28-50-6L	12.86	67.5	66.7	54.6	54.2	54.4	55.0	52.2	53.0	53.1	53.4	--	--	0.384	0.296	0.60
-7L	15.48	58.4	57.4	40.4	40.0	40.0	40.6	37.1	37.4	37.9	37.1	--	--	1.20	0.972	1.92
-7R	15.48	58.4	57.4	40.4	40.0	40.0	40.8	37.1	37.4	37.9	37.1	--	--	1.00	0.848	1.52
-8R	16.55	54.2	53.2	33.5	33.0	32.9	33.7	29.8	30.0	29.8	29.7	--	--	2.32	1.50	2.00
-8L	16.55	54.2	53.1	33.3	33.0	33.0	33.7	29.8	30.0	79.7	29.6	--	--	2.64	1.72	2.96
12-WB-13-20-1	6.96	83.8	84.0	51.0	52.2	53.3	52.8	52.2	52.1	51.9	52.0	30,000	25,000	1.93	2.08	3.07
Air Right -1	6.96	83.7	83.9	51.0	52.3	53.0	53.0	52.3	52.2	52.0	52.3	12,000	12,000	0.3	0.54	0.86
Air Left -1	6.96	83.6	84.0	51.0	52.2	52.8	53.0	52.3	52.1	52.0	52.2	35,000	25,000	1.28	2.0	2.82
-2	6.02	85.1	85.6	61.0	61.3	62.6	62.3	61.8	61.7	61.8	61.8	18,000	12,000	0.47	0.65	0.98
Air Right -2	6.02	85.2	85.5	61.1	61.5	62.2	62.4	61.7	61.5	61.9	61.8	7,000	5,500	0.184	0.20	0.31
Air Left -2	6.02	85.2	85.6	61.1	61.6	62.1	62.4	61.9	61.7	61.9	61.7	7,500	8,000	0.38	0.68	1.0
-3	5.11	86.4	86.7	68.8	69.1	70.0	69.9	69.7	69.5	69.6	69.5	1,400	1,600	0.15	0.14	0.18
Air Right -3	5.11	86.4	86.7	68.7	69.4	69.7	70.0	69.6	69.4	69.5	69.3	1,800	1,400	0.155	0.107	0.142
Air Left -3	5.11	86.5	85.1	67.9	67.7	68.4	68.6	68.2	68.3	68.2	67.9	1,600	1,600	0.17	0.162	0.19
-4	8.51	78.4	78.7	27.8	30.1	31.0	31.4	30.2	30.1	30.0	30.1	40,000	35,000	8.52	3.80	5.60
Air Right -4	8.51	78.7	78.6	28.1	30.5	31.2	31.5	30.3	30.2	29.9	30.2	12,000	18,000	0.68	1.12	1.80
Air Left -4	8.51	78.3	78.8	28.0	30.3	31.4	32.2	31.2	31.4	31.3	31.0	35,000	35,000	5.30	3.60	5.16
-5	9.66	78.4	78.5	11.7	14.6	16.0	16.2	14.7	14.8	14.6	14.7	60,000	45,000	7.60	7.04	9.76
Air Right -5	9.66	78.4	78.6	11.8	14.9	16.0	16.0	14.9	14.7	14.7	14.6	22,000	22,000	1.92	3.00	5.20
Air Left -5	9.66	78.6	78.6	11.8	15.0	16.2	16.1	14.8	14.7	14.6	14.6	5,500	45,000	6.16	6.28	8.96
12-WB-13-50-1	15.26	61.5	61.6	45.7	43.8	43.9	45.2	42.0	42.0	41.8	41.2	11,000	18,000	0.830	0.780	1.52
-1	15.26	61.6	61.8	45.2	43.8	43.9	45.1	41.5	42.0	41.9	41.6	15,000	18,000	--	--	--
Air Left -1	15.26	61.6	61.8	45.4	43.9	43.9	45.2	41.7	42.0	41.9	41.4	10,000	13,000	0.828	0.76	1.48
-2	16.82	55.3	55.4	35.0	34.1	34.2	35.8	31.2	31.7	31.8	31.1	14,000	16,000	2.48	1.72	2.84
Air Right -2	16.62	54.2	54.3	33.9	33.8	33.9	34.9	30.7	31.0	30.9	30.6	15,000	12,000	1.72	1.32	2.04
Air Left -2	16.50	53.9	54.3	34.1	33.7	33.8	34.9	30.6	31.0	30.7	30.6	15,000	17,000	2.32	1.52	2.68

DATA SUMMARY SHEET

Run No.	Discharge (cfs)	Pressure (pounds per square inch) P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	Vert. Vib. (IPS)	Horiz. Vib. (IPS)	Hydrophone (volts) 10-200 Kc	4-10 Kc	2-10 Kc
12-WB-13-50-3	13.95	64.3	64.8	49.6	49.8	49.7	50.4	47.9	48.0	47.9	47.8	6,500	8,500	0.38	0.48	0.88
Air Right -3	13.95	64.4	64.7	49.7	50.2	50.6	51.9	49.1	49.7	49.6	48.9	7,200	9,000	0.352	0.40	0.700
Air Left -3	13.95	64.3	64.6	50.1	49.9	49.7	50.8	47.9	48.3	48.0	47.7	8,000	7,500	0.420	0.42	0.84
-4	12.78	70.1	70.2	57.8	57.6	57.4	58.7	56.3	56.6	56.4	56.1	4,500	6,500	0.20	0.24	0.60
Air Right -4	12.78	70.1	70.5	57.9	57.8	57.4	58.8	56.4	56.6	56.4	56.2	3,500	6,500	0.344	0.216	0.44
Air Left -4	12.78	70.1	70.4	58.1	57.8	57.6	58.7	56.3	56.7	56.4	55.9	4,000	5,000	0.336	0.248	0.60
-5	12.06	72.0	72.2	59.9	60.5	60.5	61.6	59.5	59.7	59.4	59.2	1,700	1,500	0.112	0.172	0.336
Air Right -5	12.06	72.1	72.4	61.2	60.8	60.5	61.7	59.6	59.7	59.4	59.2	1,600	1,500	0.324	0.180	0.328
Air Left -5	12.06	72.0	72.4	61.2	60.8	60.4	61.8	59.3	59.6	59.4	59.2	1,600	1,500	0.292	0.184	0.356
12-BH-29-20-1	9.02	78.4	78.0	9.5	10.0	10.4	10.8	9.7	9.2	9.4	9.6	30,000	22,000	1.64	3.16	4.80
-2	9.02	78.4	78.0	10.0	12.8	13.5	14.4	13.0	13.1	13.4	12.8	27,000	20,000	1.76	3.52	5.48
-3	8.08	78.7	78.0	16.7	20.3	20.0	20.5	18.7	19.3	19.3	19.0	25,000	27,000	4.80	3.70	5.48
-4	7.22	80.0	80.0	29.4	31.8	31.8	32.2	30.9	31.4	31.4	31.2	13,000	13,000	4.40	2.50	3.52
12-BH-30-20-5	8.45	79.7	80.2	16.8	20.6	20.6	20.9	19.3	19.2	19.3	19.5	26,000	27,000	4.88	3.76	5.60
-6	7.64	82.0	82.4	34.5	36.8	37.3	37.7	36.4	36.4	36.5	36.4	11,000	12,000	3.72	1.94	2.76
-7	7.14	82.4	83.2	41.3	43.8	43.4	44.4	42.8	42.8	43.2	43.2	12,000	12,000	2.88	1.80	2.50
-8	6.61	82.5	82.5	46.8	49.2	49.4	49.4	48.8	49.2	48.9	48.6	9,000	8,500	1.32	0.98	1.36
-9	6.25	83.0	83.0	50.8	53.8	53.2	53.6	52.8	53.2	52.7	52.7	1,400	1,200	0.60	0.48	0.52
-10	5.84	84.0	84.7	55.5	56.8	56.9	57.8	57.0	57.3	57.2	57.1	180	220	0.069	0.026	0.035
-11	5.58	84.6	85.2	58.7	60.1	60.1	60.7	60.0	60.2	60.1	60.0	160	240	0.028	0.017	0.025
12-BG-29-20-1	4.90	84.8	84.4	-3.2	2.3	2.6	2.8	2.8	2.6	2.7	2.6	8,000	9,000	0.780	0.392	0.60
-2	4.86	84.5	84.3	-1.6	2.8	3.0	4.0	3.7	3.7	4.3	3.7	10,000	8,000	0.72	0.392	0.540
-3	4.82	84.4	84.2	+0.8	5.6	5.8	5.9	5.4	5.9	6.0	5.9	6,000	6,500	0.588	0.328	0.48
-4	4.68	84.2	84.2	6.0	10.8	10.9	11.1	10.3	11.1	11.1	11.2	6,500	7,000	0.404	0.248	0.440
12-BG-30-20-5	4.82	85.3	85.9	0.5	5.1	6.2	6.1	5.6	5.6	5.5	6.0	10,000	8,000	0.604	0.326	0.500
-6	4.62	85.4	86.0	8.3	12.6	13.2	13.9	13.2	13.2	13.2	13.4	9,000	8,000	0.360	0.230	0.496

DATA SUMMARY SHEET

Run No.	Discharge (cfs)	Pressure (pounds per square inch)										Vert. Vib. (IPS)	Horiz. Vib. (IPS)	Hydrophone (volts)		
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}			10-200 Kc	4-10 Kc	2-10 Kc
12-BG-30-20-7	4.52	85.5	86.2	12.7	16.4	17.2	17.8	17.1	17.0	17.1	17.3	6,000	7,000	0.336	0.224	0.680
-8	4.38	85.1	85.1	17.3	21.5	21.7	21.8	21.6	22.1	21.7	21.7	5,500	7,000	0.324	0.264	0.860
-9	4.27	85.3	85.1	20.9	24.8	25.0	25.3	25.2	25.5	25.4	25.2	6,500	7,000	0.312	0.280	0.880
-10	4.14	85.8	86.5	25.3	28.4	29.0	29.8	29.4	29.7	29.7	29.4	5,500	7,500	0.320	0.332	0.900
12-BG-4-20 -11	4.48	85.8	85.4	14.3	18.2	18.0	18.9	18.4	18.8	19.0	18.6	5,000	7,000	0.340	0.35	0.70
-12	4.16	86.2	86.0	26.2	29.3	29.1	29.8	29.5	29.8	30.2	29.6	7,000	7,000	0.32	0.31	0.80
-13	4.06	86.3	86.0	29.2	32.3	32.3	32.8	32.5	32.9	33.3	32.8	5,000	6,500	0.295	0.34	0.80
12-BG-4-20 -14	3.92	86.7	86.3	33.8	36.5	36.0	36.8	36.6	37.0	37.3	36.9	7,500	7,500	0.275	0.32	0.70
-15	3.75	86.8	86.4	38.1	40.7	40.4	40.9	41.0	41.3	41.4	41.0	6,000	8,000	0.26	0.298	0.62
-16	3.59	87.0	87.0	42.3	44.9	44.9	45.0	45.0	45.2	45.1	45.0	8,500	12,000	0.255	0.265	0.52
-17	3.32	87.2	87.2	49.0	51.0	50.7	51.2	51.1	51.7	52.1	51.3	6,000	8,500	0.228	0.25	0.35
-18	3.06	87.6	87.6	55.4	56.9	56.7	57.1	57.1	57.5	58.0	57.2	1,000	1,000	0.190	0.155	0.180
-19	2.92	87.6	87.6	58.1	59.9	59.6	60.0	60.1	60.2	60.4	59.9	750	950	0.172	0.128	0.165
-20	2.65	87.6	87.6	62.5	64.2	63.7	64.3	64.5	64.5	64.9	64.2	700	600	0.145	0.095	0.13
12-BF-29-20-1	4.89	84.8	84.6	-3.4	1.8	2.8	3.2	2.6	2.5	2.8	2.6	13,000	19,000	1.60	1.36	2.88
Air Right -1	4.89	84.8	84.4	-2.7	2.2	2.8	3.2	2.6	2.5	2.8	2.9	--	--	0.78	0.40	0.55
Air Left -1	4.89	84.8	84.4	-2.7	2.2	2.8	3.2	2.6	2.6	2.8	2.9	--	--	1.04	0.36	0.60
-2	4.97	84.7	84.4	-1.5	2.7	3.2	4.2	3.7	3.9	4.6	3.8	15,000	18,000	1.44	1.60	3.32
Air Right -2	4.97	84.7	84.4	-1.6	2.7	3.2	4.2	3.8	3.9	4.5	3.8	--	--	0.72	0.38	0.52
Air Left -2	4.97	84.7	84.4	-1.6	2.7	3.2	4.1	3.7	3.9	4.3	3.7	--	--	0.94	0.332	0.60
-3	5.07	84.6	84.4	0.6	5.9	5.6	5.9	5.5	6.0	6.0	6.0	18,000	15,000	0.86	2.80	4.68
Air Right -3	5.07	84.5	84.3	0.6	5.6	5.6	6.0	5.5	6.0	6.0	6.0	--	--	0.60	0.30	0.42
Air Left -3	5.07	84.5	84.4	0.6	5.6	5.5	6.0	5.4	6.0	6.0	5.9	--	--	0.80	0.308	0.692
-4	4.76	84.4	84.2	6.1	10.6	10.5	11.0	10.4	11.1	11.1	10.9	28,000	20,000	0.294	3.92	5.72
Air Right -4	4.76	84.4	84.2	6.0	10.8	10.5	11.4	10.6	11.1	11.2	10.9	--	--	0.40	0.228	0.572
Air Left -4	4.76	84.4	84.2	6.3	10.7	10.5	11.3	10.6	11.1	11.1	10.9	--	--	1.14	.336	1.12
12-BF-30-20-5	4.92	85.1	85.4	0.5	5.1	6.0	6.2	5.7	5.7	5.7	6.0	18,000	21,000	1.36	2.88	4.60

DATA SUMMARY SHEET

Run No.		Discharge (cfs)	Pressure (pounds per square inch)										Vert. Vib. (IPS)	Horiz. Vib. (IPS)	Hydrophone (volts)		
			P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}			10-200 Kc	4-10 Kc	2-10 Kc
12-BF-30-20-5																	
Air Right		4.76	85.4	85.9	0.5	5.1	6.0	6.3	5.8	5.7	5.6	6.0	6,000	7,800	0.60	0.292	0.456
Air Left	-5	4.81	85.3	85.8	0.6	5.1	5.9	6.2	5.6	5.7	5.5	5.9	11,000	12,000	0.82	0.30	0.736
	-6	4.66	85.4	86.2	8.3	12.9	12.9	13.9	13.2	13.0	13.1	13.4	27,000	28,000	3.62	4.04	6.08
Air Right	-6	4.60	85.5	86.2	8.6	12.8	13.4	13.8	13.0	13.2	13.3	13.5	6,000	6,500	0.348	0.214	0.676
Air Left	-6	4.60	85.6	86.0	8.5	12.8	13.4	13.8	13.0	13.3	13.2	13.4	9,000	8,000	0.376	0.42	1.40
	-7	4.52	85.6	86.3	12.6	16.8	17.4	17.6	17.0	17.2	17.0	17.4	23,000	29,000	4.80	4.00	6.00
Air Right	-7	4.49	85.6	86.2	12.8	16.8	17.4	17.6	17.3	17.3	17.3	17.5	6,000	6,500	0.312	0.26	0.88
Air Left	-7	4.49	85.4	86.0	12.7	16.6	17.4	17.6	17.1	17.1	17.2	17.5	8,000	9,000	0.316	0.56	1.66
	-8	4.37	85.4	85.7	17.4	21.0	22.0	22.0	21.8	22.0	21.8	21.8	23,000	23,000	0.588	0.396	5.92
Air Right	-8	4.37	85.4	85.9	17.0	21.3	21.8	22.4	21.8	22.0	21.7	21.8	6,500	8,000	0.30	0.344	1.06
Air Left	-8	4.37	85.3	85.7	17.4	21.4	21.6	22.3	21.9	22.2	21.8	21.8	8,500	9,000	0.304	0.82	2.26
	-9	4.28	85.2	85.1	20.8	24.9	25.6	25.6	24.8	25.4	25.4	25.0	25,000	26,000	6.20	3.84	5.64
Air Right	-9	4.28	85.1	85.2	20.8	24.7	25.4	25.6	25.0	25.4	25.4	25.0	7,000	7,000	0.292	0.368	1.14
Air Left	-9	4.27	85.0	85.0	20.6	24.8	25.3	25.8	25.1	25.5	25.5	25.3	13,000	12,000	0.28	0.88	2.28
	-10	4.16	85.9	86.3	25.0	28.4	28.9	29.8	29.2	29.6	29.6	29.5	20,000	23,000	6.0	3.36	4.8
Air Right	-10	4.16	85.8	86.3	25.1	28.4	29.0	29.9	29.3	29.8	29.6	29.6	6,000	5,000	0.38	0.44	1.14
Air Left	-10	4.14	85.8	86.3	25.6	28.4	29.0	29.9	29.3	29.6	29.6	29.6	10,000	12,000	0.36	0.94	2.16
12-BF-4-20	-11	4.45	85.8	85.6	14.3	18.0	18.3	18.7	18.4	18.7	18.9	18.6	30,000	20,000	4.3	3.7	5.6
Air Right	-11	4.47	85.8	85.5	14.3	18.4	18.3	18.9	18.4	18.9	19.0	18.6	7,000	9,000	0.23	0.35	0.92
Air Left	-11	4.47	85.8	85.5	14.3	18.2	18.3	18.7	18.4	18.8	18.9	18.6	7,000	11,000	0.33	0.58	1.6
	-12	4.16	86.1	86.0	25.9	29.1	29.1	29.7	29.4	29.8	30.1	29.5	22,000	28,000	4.0	3.4	4.6
Air Right	-12	4.16	86.1	86.0	26.1	29.3	29.1	29.7	29.4	29.8	30.1	29.5	8,000	9,000	0.29	0.50	1.33
Air Left	-12	4.16	86.1	86.1	26.0	29.3	29.1	29.8	29.4	29.8	30.1	29.5	11,000	11,000	0.31	0.95	2.25
	-13	4.06	86.3	86.0	29.5	32.2	32.4	32.8	32.5	33.0	33.5	32.8	14,000	20,000	3.4	3.0	4.25
Air Right	-13	4.06	86.3	86.1	29.6	32.4	32.4	32.8	32.5	33.1	33.5	32.8	7,000	8,000	0.28	0.53	1.35
Air Left	-13	4.04	86.4	86.1	29.5	32.4	32.4	32.8	32.7	33.0	33.5	32.8	9,000	8,500	0.28	0.98	2.03
	-14	3.92	86.7	86.3	33.7	36.3	36.2	36.7	36.7	37.1	37.3	36.9	16,000	10,000	3.10	2.73	3.30
Air Right	-14	3.92	86.7	86.3	33.8	36.3	36.2	36.8	36.7	37.1	37.3	36.9	7,000	9,000	0.26	0.53	1.30

DATA SUMMARY SHEET

Run No.		Discharge (cfs)	Pressure (pounds per square inch)										Vert. Vib. (IPS)	Horiz. Vib. (IPS)	Hydrophone (volts)		
			P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}			10-200 Kc	4-10 Kc	2-10 Kc
12-BF-4-20 Air Left	-14	3.92	86.7	86.3	33.7	36.3	36.2	36.8	36.7	37.1	37.3	36.9	10,000	12,000	0.275	1.10	1.97
	-15	3.75	86.8	86.4	38.1	40.4	40.4	40.9	40.8	41.0	41.6	41.0	14,000	16,000	2.80	2.25	2.85
Air Right	-15	3.75	86.8	86.4	38.2	40.4	40.4	40.9	40.8	41.0	41.6	41.0	6,000	6,500	0.235	0.53	1.05
Air Left	-15	3.75	86.8	86.4	38.2	40.4	40.4	40.9	40.8	41.2	41.7	41.0	9,000	9,500	0.26	0.97	1.53
	-16	3.59	87.0	86.8	42.4	44.7	45.0	45.0	44.9	45.1	45.0	45.0	8,500	9,500	2.38	1.83	2.55
Air Right	-16	3.59	87.0	86.9	42.4	44.8	45.0	45.2	44.9	45.1	45.0	45.0	8,000	9,000	0.225	0.45	0.87
Air Left	-16	3.59	87.0	86.9	42.4	44.7	45.0	45.0	44.9	45.1	45.0	45.0	12,000	14,000	0.25	0.73	1.15
	-17	3.32	87.2	87.3	48.8	51.0	50.7	51.1	51.1	51.7	52.1	51.3	8,000	4,500	1.43	0.94	1.18
Air Right	-17	3.32	87.2	87.2	48.8	51.0	50.7	51.1	51.1	51.7	52.1	51.3	8,500	5,000	0.195	0.39	0.54
Air Left	-17	3.32	87.2	87.2	48.8	51.0	50.7	51.2	51.1	51.7	52.1	51.3	8,500	7,000	0.22	0.64	0.90
	-18	3.06	87.6	87.7	55.2	56.8	56.6	57.2	57.1	57.5	58.0	57.2	800	500	1.00	0.27	0.29
Air Right	-18	3.06	87.6	87.6	55.2	56.8	56.6	57.1	57.1	57.5	58.0	57.2	800	500	0.175	0.190	0.225
Air Left	-18	3.06	87.6	87.6	55.2	56.9	56.5	57.1	57.1	57.5	58.0	57.2	800	500	0.190	0.258	0.275
	-19	2.92	87.6	87.6	57.9	59.8	59.3	59.8	59.9	60.2	60.4	59.9	22	26	0.14	0.028	0.032
Air Right	-19	2.92	87.6	87.6	58.0	59.8	59.2	59.8	59.9	60.2	60.4	59.9	800	700	0.16	0.145	0.17
Air Left	-19	2.92	87.6	87.6	58.0	59.8	59.3	59.8	60.0	60.2	60.4	59.9	700	900	0.18	0.163	0.183
12-BF-5-35	-1	8.04	80.8	80.9	20.7	26.2	27.2	27.7	26.6	26.8	26.8	26.8	27,000	26,000	7.12	3.72	5.2
	-2	7.68	81.2	81.3	25.9	31.2	31.8	32.4	31.4	31.8	31.7	31.7	18,000	18,000	5.04	3.12	4.36
	-3	7.39	81.9	82.0	30.8	35.7	35.9	36.7	36.1	36.2	36.2	36.1	13,000	15,000	3.1	2.43	3.6
	-4	7.08	82.3	82.6	35.4	40.2	40.2	40.8	40.2	40.3	40.3	40.1	8,500	9,000	2.3	2.05	2.6
	-5	6.91	82.4	82.6	38.8	42.6	43.4	43.6	43.4	43.5	43.2	43.1	9,000	9,500	1.75	1.64	2.35
	-6	6.67	82.8	82.9	41.8	45.6	46.2	46.4	46.2	46.2	46.0	45.9	7,500	8,500	1.52	1.38	1.95
	-7	6.42	83.0	83.3	44.8	48.4	48.6	49.1	49.0	49.0	48.8	48.6	6,000	7,000	1.06	0.90	1.20
	-8	6.28	83.2	83.5	46.8	50.2	50.5	50.8	50.8	50.8	50.5	50.3	4,000	4,500	0.77	0.67	0.76
	-9	6.08	83.5	83.7	49.3	52.8	52.8	53.1	53.2	53.2	53.1	52.7	1,300	1,400	0.38	0.32	0.34
	-10	5.96	83.7	84.0	50.8	53.8	54.1	54.3	54.6	54.5	54.2	54.1	500	600	0.275	0.17	0.20
	-11	5.83	84.3	84.4	53.2	55.6	55.7	56.4	56.1	56.2	56.7	55.9	400	500	0.145	0.092	0.095

DATA SUMMARY SHEET

Run No.	Discharge (cfs)	Pressure (pounds per square inch)										Vert. Vib. (IPS)	Horiz. Vib. (IPS)	Hydrophone (volts)		
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}			10-200 Kc	4-10 Kc	2-10 Kc
12-BF-5-35-12	5.46	84.9	85.4	57.7	59.7	59.8	60.5	60.1	60.3	60.7	60.0	200	260	0.05	0.03	0.052
-13	8.44	80.1	80.7	14.2	20.1	21.3	22.2	20.7	21.0	21.0	20.7	27,000	27,000	8.60	4.12	5.48
12-BF-6-35-14	9.00	78.4	78.3	5.6	12.4	14.2	14.2	12.6	13.0	12.6	12.8	27,000	26,000	5.76	4.96	6.24
-15	9.25	77.8	77.6	2.0	9.1	11.0	10.8	9.1	9.8	9.3	9.6	26,000	26,000	3.52	5.12	6.24
12-BF-6-50-1	14.16	64.3	64.3	15.2	22.8	25.4	25.6	22.1	22.6	22.8	22.3	25,000	26,000	11.60	6.08	6.92
Air Right -1	14.16	64.1	64.3	15.2	22.8	25.3	25.7	22.0	22.7	22.7	22.4	21,000	22,000	2.08	4.52	6.00
Air Left -1	14.16	64.2	64.3	15.1	22.8	25.1	25.6	22.1	22.8	22.6	22.2	20,000	19,000	0.88	2.56	4.44
-2	13.75	65.8	65.8	19.3	26.6	28.1	29.0	26.3	26.6	26.3	26.1	26,000	23,000	11.88	5.12	6.48
Air Right -2	13.75	65.8	65.8	19.3	26.6	28.0	29.1	26.3	26.6	26.3	26.1	25,000	24,000	1.92	3.6	5.2
Air Left -2	13.75	65.8	65.8	19.3	26.6	28.1	29.1	26.3	26.6	26.3	26.2	20,000	14,000	0.74	2.36	3.72
-3	13.44	66.8	66.8	22.6	29.0	30.9	31.7	28.6	29.2	29.0	29.0	20,000	18,000	9.88	4.52	5.68
Air Right -3	13.44	66.8	66.8	22.8	29.0	30.9	31.8	28.6	29.2	29.0	29.0	30,000	18,000	1.68	3.24	4.48
Air Left -3	13.44	66.8	66.8	22.6	29.0	30.9	31.8	28.6	29.2	29.0	29.0	15,000	20,000	0.64	2.00	3.24
-4	12.72	69.5	69.4	30.4	35.7	37.5	38.2	35.7	36.0	36.3	36.1	20,000	16,000	5.00	2.76	3.68
Air Right -4	12.72	69.7	69.4	30.4	35.8	37.5	38.2	35.7	36.1	36.3	36.1	16,000	11,000	0.94	2.2	2.96
Air Left -4	12.72	69.5	69.4	30.4	35.8	37.5	38.2	35.7	36.1	36.2	36.1	13,000	11,000	0.472	1.32	2.12
-5	12.11	71.2	70.8	35.1	40.0	41.4	42.2	39.8	40.4	40.4	40.1	11,000	10,000	2.48	1.52	2.00
Air Right -5	12.11	71.2	70.8	34.9	40.0	41.4	42.2	39.8	40.4	40.4	40.1	15,000	9,000	0.708	1.60	2.00
Air Left -5	12.11	71.2	70.8	34.9	40.0	41.5	42.2	39.9	40.4	40.4	40.1	10,000	8,000	0.368	0.980	1.48
-6	11.59	72.5	72.2	39.2	44.1	45.1	45.9	43.8	44.3	43.9	44.2	6,800	8,000	1.0	0.73	1.1
Air Right -6	11.59	72.5	72.2	39.2	44.2	45.1	45.9	43.8	44.2	44.2	44.2	6,700	8,000	0.56	1.13	1.40
Air Left -6	11.59	72.5	72.1	39.2	44.2	45.1	45.9	43.8	44.3	44.2	44.2	5,000	6,500	0.31	0.75	1.06
-7	11.18	73.9	73.4	43.0	47.9	48.5	49.3	47.5	47.8	47.8	47.7	5,000	5,500	0.49	0.44	0.60
Air Right -7	11.18	73.9	73.4	42.9	47.9	48.5	49.3	47.5	47.7	47.8	47.7	3,700	6,000	0.44	0.75	0.90
Air Left -7	11.18	73.9	73.4	42.9	47.9	48.5	49.2	47.5	47.9	47.6	47.7	2,500	5,000	0.275	0.55	0.74
-8	7.97	81.0	80.7	64.8	67.6	67.0	68.4	67.8	67.9	68.0	67.9	110	90	0.120	0.026	0.045

DATA SUMMARY SHEET

Run No.	Discharge (cfs)	Pressure (pounds per square inch)										Vert. Vib. (IPS)	Horiz. Vib. (IPS)	Hydrophone (volts)		
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}			10-200 Kc	4-10 Kc	2-10 Kc
12-BF-6-50																
Air Right -8	7.97	81.0	80.6	64.9	67.7	67.0	68.4	67.8	67.9	68.0	67.9	770	900	0.18	0.111	0.126
Air Left -8	7.97	81.0	80.6	64.9	67.6	67.0	68.4	67.8	67.9	68.0	67.9	720	800	0.162	0.170	0.203
-9	10.08	76.6	76.0	51.6	55.4	55.7	56.8	55.1	55.3	55.4	55.4	2,300	2,200	0.17	0.24	0.27
Air Right -9	10.08	76.6	76.1	51.6	55.5	55.7	56.8	55.1	55.3	55.4	55.4	2,400	1,700	0.272	0.283	0.35
Air Left -9	10.08	76.6	76.0	51.6	55.4	55.7	56.8	55.1	55.3	55.4	55.4	1,600	2,000	0.213	0.275	0.34
-10	8.10	81.5	80.9	65.1	67.6	67.8	68.1	67.7	67.4	67.4	67.7	80	45	--	--	--
-10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
-10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12-BF-9-50-11	15.49	60.8	60.8	5.0	12.8	15.7	16.1	12.6	12.6	12.5	12.3	35,000	45,000	10.08	9.60	11.48
Air Right -11	15.49	60.8	60.8	4.8	13.0	15.6	16.4	12.6	12.5	12.5	12.3	21,000	26,000	3.20	5.76	4.60
Air Left -11	15.49	60.8	60.8	4.8	13.0	15.7	16.2	12.5	12.5	12.5	12.3	20,000	14,000	2.12	3.80	6.60
12-BG-6-50-1	14.26	64.1	64.2	15.1	22.7	25.2	25.1	22.0	22.7	22.5	22.1	10,000	10,000	0.568	0.760	1.96
-2	13.69	65.8	65.9	19.5	26.6	28.0	29.4	26.2	26.4	26.3	26.2	20,000	14,000	0.552	0.728	1.84
-3	13.44	66.8	66.8	22.7	28.9	30.6	31.6	28.6	29.2	29.2	29.0	13,000	10,000	0.492	0.700	1.72
-4	12.62	69.5	69.5	30.3	35.6	36.7	38.4	35.7	36.3	36.4	36.2	7,000	9,000	0.40	0.588	1.16
-5	12.11	71.2	71.2	34.6	40.1	41.2	42.2	39.8	40.4	40.4	40.2	8,000	7,000	0.368	0.452	0.88
-6	11.59	72.5	72.2	39.2	44.4	44.8	45.7	43.9	44.2	44.3	44.2	3,600	6,000	0.290	0.37	0.67
-7	11.16	73.9	73.5	43.1	48.1	48.1	49.4	47.4	47.7	47.8	47.7	3,000	4,200	0.285	0.30	0.60
-8	8.00	81.0	80.7	65.0	67.6	67.4	68.1	67.7	67.7	68.1	67.9	550	400	0.16	0.11	0.13
-9	10.48	76.6	76.2	51.6	55.1	55.7	56.6	55.1	55.5	55.6	55.4	1,300	2,000	0.252	0.23	0.263
12-BG-9-50-10	15.30	60.8	60.8	4.8	13.1	15.8	16.1	12.6	12.5	12.5	12.3	18,000	17,000	1.12	1.36	3.20
12-BH-6-50-1	15.70	60.3	60.3	22.8	28.8	30.6	30.8	26.8	27.6	27.4	27.0	13,000	12,000	7.04	3.32	4.20
-2	15.12	62.4	62.4	27.3	33.6	33.7	35.0	31.4	31.8	31.3	31.7	12,000	13,000	4.76	2.44	3.16
-3	14.80	63.8	63.6	30.7	35.6	36.7	37.7	34.0	34.5	34.6	34.3	9,000	10,000	2.88	1.64	2.14
-4	13.68	67.4	67.1	38.6	42.4	43.2	44.4	41.4	42.1	42.1	41.6	2,700	6,500	0.54	0.45	0.60
-5	13.04	69.2	69.1	43.1	46.9	47.4	48.1	45.8	46.0	46.4	46.1	3,100	2,900	0.25	0.25	0.30

DATA SUMMARY SHEET

Run No.	Discharge (cfs)	Pressure (pounds per square inch)										Vert. Vib. (IPS)	Horiz. Vib. (IPS)	Hydrophone (volts)		
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}			10-200 Kc	4-10 Kc	2-10 Kc
12-BH-6-50 -6	10.08	77.6	76.8	62.0	64.2	64.3	64.7	63.4	63.7	63.7	63.6	90	150	0.113	0.024	0.040
12-BH-9-50 -7	17.18	55.5	55.4	11.2	18.0	19.8	20.3	15.7	15.7	15.8	15.5	24,000	22,000	12.0	6.16	7.08
12-BF-9-70 -1	19.90	41.6	41.9	18.3	23.7	26.3	26.7	21.3	21.2	20.8	20.7	16,000	16,000	5.6	2.88	3.52
-2	19.32	45.6	45.7	24.0	28.5	31.3	31.5	26.7	26.7	26.5	26.2	10,000	8,000	2.80	1.64	2.24
-3	17.75	50.8	50.7	32.9	36.7	38.5	39.2	34.7	35.0	35.5	34.3	7,000	6,000	0.68	0.48	0.78
-4	16.92	53.9	54.0	36.9	40.8	42.7	42.8	39.0	39.2	39.7	38.6	7,000	4,000	0.40	0.38	0.56
-5	16.55	56.4	56.6	40.4	44.2	45.6	46.5	42.5	42.9	43.0	42.4	6,000	3,000	0.21	0.30	0.44
-6	15.80	59.4	59.5	44.8	47.8	49.5	50.2	46.4	46.8	46.8	46.4	2,000	2,400	0.17	0.18	0.25
-7	14.70	63.5	63.6	51.0	53.9	54.6	55.5	52.3	52.8	52.0	52.1	1,800	1,000	0.115	0.14	0.18
-8	13.30	68.2	68.3	58.1	60.4	61.2	61.8	59.3	59.5	59.6	59.2	280	160	0.06	0.05	0.075
-9	18.00	51.3	51.4	33.7	37.5	38.6	39.4	34.9	35.5	35.7	34.7	6,500	5,000	0.68	0.48	0.78
12-BF-10-20-1	4.42	87.3	79.2	4.6	8.1	9.3	9.3	9.0	9.1	9.4	9.2	27,000	21,000	2.28	4.08	6.16
-2	4.22	87.5	80.1	15.1	17.8	19.3	19.3	18.9	19.3	19.6	19.0	36,000	30,000	5.56	4.52	7.40
-3	4.06	87.4	80.6	21.4	23.7	25.1	25.3	25.0	25.5	25.8	25.0	25,000	24,000	7.40	4.40	7.16
-4	3.96	87.4	81.0	25.2	27.8	29.1	29.1	29.0	29.4	29.5	29.0	24,000	25,000	7.08	3.84	5.44
-5	3.72	87.5	82.1	32.7	34.8	36.1	36.3	35.9	36.5	36.6	36.0	22,000	22,000	6.16	3.04	4.08
-6	3.65	87.7	83.4	36.7	38.7	39.8	40.0	39.7	40.3	40.4	39.8	19,000	17,000	3.88	2.75	3.6
-7	3.41	87.7	83.4	42.8	45.1	45.6	46.0	45.5	45.8	46.1	45.8	13,000	12,000	3.09	2.18	2.9
-8	3.20	88.0	84.1	47.6	49.8	50.3	50.8	50.2	50.6	51.0	50.3	13,000	14,000	2.32	1.58	2.0
-9	3.02	88.0	84.6	51.7	53.8	54.0	54.5	54.2	54.5	54.8	54.4	5,000	4,000	1.05	0.68	0.79
-10	2.94	88.1	85.1	54.4	56.5	56.6	57.0	56.6	56.9	57.2	56.8	1,400	1,300	0.37	0.23	0.265
-11	2.70	88.3	85.3	56.8	58.6	58.4	59.1	58.9	59.2	59.8	58.9	220	230	0.14	0.058	0.07
12-BF-11-50-7	7.85	81.9	55.8	49.6	51.2	51.7	51.9	50.8	51.2	50.4	50.7	5,000	6,500	0.33	0.46	0.67
-8	7.56	82.3	57.8	52.2	53.8	54.0	54.4	53.4	53.7	53.0	53.3	4,000	4,500	0.25	0.40	0.56
-9	7.10	83.0	61.1	56.0	57.2	57.3	58.0	57.0	57.2	57.8	57.2	3,500	4,000	0.14	0.20	0.31

DATA SUMMARY SHEET

Run No.	Discharge (cfs)	Pressure (pounds per square inch)										Vert. Vib. (IPS)	Horiz. Vib. (IPS)	Hydrophone (volts)		
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}			10-200 Kc	4-10 Kc	2-10 Kc
12-BF-11-50-10	5.69	85.6	71.6	68.3	69.7	69.3	69.7	69.3	69.4	69.8	69.5	110	110	.044	.017	.035
-11	9.30	78.8	41.6	33.2	35.6	35.9	36.3	35.6	35.2	34.6	35.2	16,000	22,000	3.80	2.52	3.6
-12	8.70	79.7	45.4	38.0	40.2	40.4	40.8	39.5	39.6	39.5	39.6	16,000	18,000	2.40	1.70	2.56
-13	8.25	80.8	50.6	43.8	45.8	45.8	46.2	44.9	45.2	45.4	45.2	10,000	12,000	1.16	0.92	1.44
-14	10.06	76.8	33.5	23.7	26.4	26.8	27.2	25.6	25.8	25.8	25.7	24,000	28,000	7.00	3.28	4.64
-15	10.67	75.3	26.8	16.0	18.8	19.1	19.7	17.8	18.1	17.9	18.1	32,000	30,000	8.36	4.16	5.64
-16	10.88	74.5	22.9	11.6	14.2	14.7	15.2	13.3	13.6	12.9	13.4	40,000	35,000	7.72	5.28	6.64
12-BF-6-50 -2	13.82	65.9	--	18.8	26.5	28.2	28.8	26.1	26.1	25.8	25.8	23,000	24,000	10.40	5.68	6.68
Air Right -2	--	--	--	--	--	--	--	--	--	--	--	--	--	1.84	4.16	5.52
Air Left -2	--	--	--	--	--	--	--	--	--	--	--	--	--	0.744	2.20	3.92
-2	--	65.9	--	18.7	26.3	28.2	28.7	26.0	26.0	25.9	26.1	9,000	9,000	0.576	--	--
12-BF-6-50 -5	12.16	71.2	--	34.0	39.9	41.4	41.6	40.0	39.8	39.7	40.0	10,000	11,000	2.76	1.80	2.48
Air Right -5	--	--	--	--	--	--	--	--	--	--	--	--	--	0.80	1.80	2.28
Air Left -5	--	--	--	--	--	--	--	--	--	--	--	--	--	0.412	1.12	1.624
12-BG-6-50 -5	--	71.2	--	33.8	40.0	41.4	41.8	39.9	39.7	39.5	40.1	7,000	8,000	0.376	0.52	0.988
-9	10.08	76.6	--	51.1	55.6	56.0	56.6	55.4	55.2	54.7	55.5	1,700	1,900	0.192	0.144	0.176
Air Right -9	--	--	--	--	--	--	--	--	--	--	--	--	--	0.34	0.308	0.344
Air Left -9	--	--	--	--	--	--	--	--	--	--	--	--	--	0.292	0.30	0.368
12-BG-6-50 -9	--	76.6	--	51.2	55.6	56.1	56.6	55.2	54.9	54.6	55.4	1,800	1,800	0.356	2.16	0.28
12-BF-30-20-7	4.52	85.5	--	12.5	17.0	17.0	17.6	17.0	17.1	17.4	17.4	31,000	30,000	4.00	3.80	5.84
Air Right -7	--	--	--	--	--	--	--	--	--	--	--	--	--	0.32	0.34	1.032
Air Left -7	--	--	--	--	--	--	--	--	--	--	--	--	--	0.352	0.70	1.96
12-BG-30-20-7	--	85.6	--	12.4	17.0	17.1	17.5	17.1	17.2	17.4	17.4	7,000	9,000	0.32	0.28	0.78
12-BF-4-20-13	4.52	86.3	--	28.6	32.2	32.3	32.8	32.6	32.5	33.0	32.8	23,000	21,000	4.40	3.20	4.64
Air Right -13	--	--	--	--	--	--	--	--	--	--	--	--	--	0.352	0.48	1.20
Air Left -13	--	--	--	--	--	--	--	--	--	--	--	--	--	0.372	1.12	2.20
12-BG-4-20 -13	--	86.3	--	28.6	32.5	32.6	32.8	32.4	32.7	32.8	32.9	7,000	6,000	0.388	0.42	0.84

DATA SUMMARY SHEET

Run No.	Discharge (cfs)	Pressure (pounds per square inch)										Vert. Vib. (IPS)	Horiz. Vib. (IPS)	Hydrophone (volts)		
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}			10-200 Kc	4-10 Kc	2-10 Kc
12-BF-4-20-16	3.59	87.0	--	41.5	44.5	44.6	44.8	44.6	44.8	44.8	44.9	12,000	13,000	2.60	2.02	2.71
Air Right -16	--	--	--	--	--	--	--	--	--	--	--	--	--	0.21	0.46	0.91
Air Left -16	--	--	--	--	--	--	--	--	--	--	--	--	--	0.26	1.00	1.49
12-BG-4-20-16	--	87.0	--	41.4	44.6	44.5	44.8	44.7	44.7	44.9	45.0	6,000	12,000	0.27	0.26	0.57
12-BF-4-20-19	2.91	87.6	--	57.3	59.5	59.0	59.4	59.7	59.2	59.6	59.6	120	200	0.120	0.034	0.037
Air Right -19	--	--	--	--	--	--	--	--	--	--	--	--	--	0.164	0.142	0.167
Air Left -19	--	--	--	--	--	--	--	--	--	--	--	--	--	0.173	0.176	0.194
12-BG-4-20-19	--	87.6	--	57.3	59.7	59.2	59.5	59.7	59.4	59.8	59.9	750	800	0.190	0.132	0.167

PARAMETER SUMMARY SHEET

Run No.	Valve Opening	σ	K	Dynamic Pressure	Mean Pressure	Dynamic Pressure / Mean Pressure	$C_d = \frac{Q}{A\sqrt{2gh}}$
12-WB-12-20-1	20%	1.78	1.74	0.72	44.4	0.0160	0.129
-2		2.20	2.14	0.50	50.0	0.0100	0.125
-3		2.47	2.41	0.48	51.9	0.0092	0.125
-4		2.70	2.62	0.50	54.0	0.0093	0.124
-5		2.98	2.90	0.45	56.5	0.0080	0.124
-6		3.33	3.25	0.42	58.3	0.0072	0.126
-7		3.66	3.57	0.40	60.3	0.0066	0.125
-8		3.99	3.89	0.37	61.8	0.0060	0.127
-9		4.18	4.08	0.72	62.6	0.0120	0.124
-10		4.96	4.82	0.38	65.2	0.0058	0.128
-11		5.86	5.72	0.35	68.0	0.0051	0.125
-12		3.56	3.47	0.48	59.1	0.0081	0.128
-13		1.62	1.57	1.83	41.3	0.0440	0.128
-14		1.26	1.22	2.23	35.7	0.0620	0.127
-15		0.886	0.86	2.73	25.7	0.1460	0.126
-16		0.606	0.58	2.36	17.2	0.1370	0.125
-17		0.445	0.43	2.26	11.5	0.1970	0.123
-18		0.518	0.50	2.03	19.1	0.1060	0.124
-19		0.359	0.34	2.36	6.85	0.3440	0.122
-20		0.292	0.28	2.75	3.65	0.7530	0.121

PARAMETER SUMMARY SHEET - continued:

Run No.	Valve Opening	σ	K	Dynamic Pressure	Mean Pressure	Dynamic Pressure / Mean Pressure	$C_d = \frac{Q}{A\sqrt{2gh}}$
12-WB-13-35-1	35%	1.16	0.99	2.03	28.90	0.070	0.236
-2		1.37	1.27	1.93	32.65	0.059	0.232
-3		0.87	0.81	2.10	23.55	0.089	0.232
-4		0.65	0.59	1.87	17.60	0.106	0.224
-5		1.69	1.59	3.12	38.90	0.080	0.230
-6		1.89	1.77	1.25	42.00	0.030	0.232
-7		2.08	1.95	1.17	44.05	0.027	0.232
-8		2.60	2.43	0.93	49.45	0.019	0.234
-9		2.79	2.62	0.67	50.80	0.013	0.231
-10		3.03	2.85	0.68	52.50	0.013	0.230
-11		3.29	3.09	0.67	54.30	0.012	0.231
-12		4.60	4.34	0.48	60.70	0.008	0.231
-13		3.33	3.13	0.62	54.30	0.011	0.218
-14		3.83	3.62	0.87	56.20	0.015	0.216
12-WB-13-50-1	50%	2.00	1.66	2.20	33.20	0.066	0.350
-2		2.22	1.95	2.07	37.20	0.056	0.346
-3		2.48	2.17	1.83	39.80	0.046	0.345
-4		2.50	2.21	1.90	39.10	0.049	0.339
-5		2.76	2.45	1.73	41.60	0.042	0.341
-6		3.11	2.71	1.73	45.00	0.038	0.336
-7		3.71	3.31	1.32	48.40	0.027	0.330
-8		4.12	3.67	1.32	50.10	0.026	[illegible]

PARAMETER SUMMARY SHEET - continued:

Run No.	Valve Opening	σ	K	Dynamic Pressure	Mean Pressure	$\frac{\text{Dynamic Pressure}}{\text{Mean Pressure}}$	$C_d = \frac{Q}{A\sqrt{2gh}}$
12-WB-13-50-9	50%	4.35	3.89	1.27	53.20	0.024	0.324
-10		5.59	5.02	1.10	57.60	0.019	0.324
-11		6.53	5.86	0.92	60.20	0.015	0.325
-12		7.44	6.68	0.97	62.30	0.016	0.325
-13		9.56	8.61	0.81	66.60	0.012	0.325
-14		11.30	10.19	0.88	70.00	0.013	0.325
-15		5.00	4.49	1.19	55.00	0.022	0.326
12-WB-14-50-16	50%	1.60	1.38	1.23	10.20	0.121	0.355
12-WB-14-70-1	70%	4.47	3.34	0.45	40.25	0.0111	0.567
-2		4.82	3.63	0.425	41.70	0.0101	0.569
-3		5.26	3.95	0.425	43.65	0.0097	0.568
-4		6.20	4.62	0.400	47.40	0.0084	0.575
-5		6.64	5.00	0.37	49.20	0.0075	0.567
-6		9.30	6.83	0.32	54.9	0.0058	0.595
12-WB-15-70-7		9.47	7.12	0.60	56.8	0.0105	0.571
-8		10.90	8.20	0.36	58.3	0.0061	0.581
-9		12.60	9.34	0.37	61.0	0.0060	0.582
-10		6.03	4.58	0.54	47.7	0.0113	0.572
-11		6.70	5.06	0.70	49.8	0.0140	0.567
-12		6.56	4.96	0.55	49.2	0.0111	0.565
-13		7.08	5.37	0.51	51.2	0.0099	0.557

PARAMETER SUMMARY SHEET - continued:

Run No.	Valve Opening	σ	K	Dynamic Pressure	Mean Pressure	Dynamic Pressure / Mean Pressure	$C_d = \frac{Q}{A\sqrt{2gh}}$
2-WB-15-70-14	70%	8.26	6.22	0.55	54.2	0.0101	0.567
-15		5.09	4.56	0.73	42.4	0.0173	0.576
-16		5.08	4.59	0.75	44.0	0.0170	0.564
2-WB-20-20-1	20%	0.37	0.349	5.31	7.80	0.681	
-2		0.46	0.435	2.65	11.6	0.228	
-3		0.64	0.613	2.62	19.2	0.136	
2-WB-21-20-4		0.80	0.763	2.46	24.7	0.100	
-5		0.93	0.899	2.46	28.4	0.087	
-6		1.19	1.149	2.58	35.4	0.073	
-7		1.71	1.657	1.87	43.4	0.043	
-8		2.07	1.999	0.92	47.8	0.019	
-9		2.46	2.383	0.70	52.2	0.013	
-10		3.96	3.847	0.42	62.4	0.007	
-11		4.75	4.600	0.40	63.5	0.006	
-12		6.64	6.451	0.37	70.7	0.005	
-13		9.89	9.632	0.31	75.4	0.004	
2-WB-22-20-1	20%	2.68	2.606	Tape Recorder Broken			
-2		3.05	2.964				
-3		2.83	2.752				
-4		3.57	3.477				
-5		0.64	0.618				

PARAMETER SUMMARY SHEET - continued:

Run No.	Valve Opening	σ	K	Dynamic Pressure	Mean Pressure	Dynamic Pressure / Mean Pressure	$C_d = \frac{Q}{A\sqrt{2gh}}$
12-WB-22-20-6	20%	0.45	0.429	2.65	11.9	0.223	
-7		0.37	0.350	2.69	8.0	0.336	
12-WC-21-20-1	20%	7.26	6.944	0.27	70.7	0.004	
-2		7.82	7.165	0.25	71.0	0.004	
-3		13.05	12.468	0.33	76.3	0.004	
-4		5.55	5.307	Tape Recorder Broken			
-5		5.03	4.818				
-6		6.57	6.294				
-7		1.10	1.041	2.10	31.8	0.066	
-8		1.36	1.293	2.01	37.4	0.054	
-9		1.63	1.551	1.67	42.1	0.040	
-10		1.98	1.888	1.23	46.2	0.027	
-11		2.80	2.674	0.65	53.8	0.012	
-12		3.63	3.474	0.45	59.0	0.008	
-13		4.54	4.343	0.40	63.1	0.006	
-14		0.76	0.719	1.78	22.0	0.081	
-15		0.59	0.554	2.23	16.4	0.136	
12-WB-27-20-1	20%	0.371	0.351	2.69	11.65	0.2309	
-2		0.438	0.416	2.72	10.7	0.2542	
-3		0.597	0.572	2.84	23.7	0.1198	
-4		0.735	0.706	2.77	27.6	0.1004	

PARAMETER SUMMARY SHEET - continued:

Run No.	Valve Opening	σ	K	Dynamic Pressure	Mean Pressure	$\frac{\text{Dynamic Pressure}}{\text{Mean Pressure}}$	$C_d = \frac{Q}{A\sqrt{2gh}}$
2-WB-27-20-5	20%	0.859	0.827	2.71	30.3	0.0894	
-6		1.146	1.113	2.71	39.5	0.0686	
-7		1.497	1.450	2.32	44.8	0.0518	
-8		1.897	1.840	1.48	51.4	0.0288	
-9		2.274	2.204	1.10	55.1	0.0120	
-10		1.512	1.464	2.50	42.7	0.0585	
-11		1.711	1.667	2.00	45.1	0.0443	
-12		2.837	2.756	0.93	57.7	0.0161	
-13		1.984	1.925	1.47	49.1	0.0299	
-14		3.663	3.560	1.17	62.6	0.0187	
-15		4.874	4.744	0.70	67.1	0.0104	
-16		5.950	5.795	0.43	70.2	0.0061	
-17		6.927	6.746	0.43	72.2	0.0060	
2-WB-28-50-1	50%	9.639	8.488	0.62	68.1	0.0091	
-2		5.290	4.674	1.14	58.0	0.0197	
-3		5.983	5.299	1.03	61.4	0.0168	
-4		6.972	6.206	1.14	64.8	0.0176	
-5		3.294	2.915	1.58	48.9	0.0323	
-6		4.432	3.915	1.43	54.8	0.0261	
-7		2.395	2.098	2.07	40.4	0.0512	
-8		1.773	1.549	2.45	33.3	0.0736	

PARAMETER SUMMARY SHEET - continued:

Run No.	Valve Opening	σ	K	Dynamic Pressure	Mean Pressure	Dynamic Pressure / Mean Pressure	$C_d = \frac{Q}{A\sqrt{2gh}}$
12-WB-28-50-5L	50%	3.294	2.915	1.58	48.9	0.0323	
-6L		4.432	3.915	1.43	54.8	0.0261	
-7L		2.395	2.098	2.07	40.4	0.0512	
-8L		1.773	1.549	2.45	33.3	0.0736	
12-WB-13-20-1	20%	2.04	1.981	This was not recorded			.129
-2		3.21	3.117				.129
-3		4.88	4.747				.129
-4		0.89	0.859				.128
-5		0.44	0.413				.131
12-WB-13-50-1	50%	2.68	2.341				.353
-2		1.83	1.589				.357
-3		3.70	3.225				.359
-4		4.94	4.331				.355
-5		5.65	4.958				.352

PARAMETER SUMMARY SHEET

Run No.	Valve Opening	σ	K	Dynamic Pressure	Mean Pressure	Dynamic Pressure / Mean Pressure	$C_d = \frac{Q}{A\sqrt{2gh}}$
12-BH-29-20-1	20%	0.314	0.310	3.34	5.78	0.579	
-2		0.378	0.373	1.50	10.5	0.143	
-3		0.519	0.513	1.43	16.5	0.087	
-4		0.885	0.874	1.03	29.4	0.035	
12-BH-30-20-5		0.523	0.516	1.33	16.4	0.081	
-6		1.061	1.047	0.76	34.0	0.022	
-7		1.408	1.389	0.78	41.0	0.019	
-8		1.788	1.764	0.68	46.7	0.015	
-9		2.135	2.107	0.73	50.7	0.014	
-10		2.513	2.480	0.450	55.3	0.008	
-11		2.927	2.888	0.400	58.7	0.007	
12-BG-29-20-1	20%	0.178	0.177	5.80	-17.8	0.326	0.056
-2		0.194	0.194	5.93	-9.0	0.659	0.058
-3		0.228	0.227	0.99	0.9	1.100	0.059
-4		0.318	0.317	1.14	6.8	0.168	0.058
12-BG-30-20-5		0.227	0.226	0.95	0.9	1.056	0.057
-6		0.353	0.352	1.40	8.7	0.161	0.057
-7		0.430	0.428	1.0	12.4	0.081	0.057
-8		0.532	0.530	0.800	17.2	0.046	0.058
-9		0.619	0.617	0.81	20.9	0.039	0.058
-10		0.734	0.731	0.550	25.7	0.021	0.058
12-BG-4-20-11		0.455	0.454	0.99	14.1	0.070	0.057

PARAMETER SUMMARY SHEET - continued:

Run No.	Valve Opening	σ	K	Dynamic Pressure	Mean Pressure	$\frac{\text{Dynamic Pressure}}{\text{Mean Pressure}}$	$C_d = \frac{Q}{A\sqrt{2gh}}$
12-BG-4-20-12	20%	0.735	0.732	0.550	26.4	0.021	0.058
-13		0.837	0.834	0.72	32.0	0.022	0.058
-14		0.982	0.978	0.450	33.8	0.013	0.058
-15		1.157	1.155	0.420	38.1	0.011	0.058
-16		1.357	1.354	0.330	42.3	0.008	0.058
-17		1.763	1.758	0.310	49.0	0.006	0.058
-18		2.276	2.269	0.280	55.0	0.005	0.058
-19		2.596	2.586	0.220	58.2	0.004	0.058
-20		3.256	3.242	0.210	62.8	0.003	0.057
12-BF-29-20-1	20%	0.178	0.177	3.17	3.12	1.016	0.056
-2		0.195	0.195	3.24	2.02	1.604	0.058
-3		0.229	0.228	1.07	1.0	1.07	0.060
-4		0.313	0.312	0.99	6.2	0.160	0.054
12-BF-30-20-5		0.228	0.227	0.99	0.8	0.124	0.058
-6		0.353	0.352	1.20	9.6	0.125	0.058
-7		0.431	0.428	1.50	12.8	0.117	0.058
-8		0.531	0.530	1.44	17.5	0.082	0.058
-9		0.615	0.613	0.91	20.7	0.044	0.058
-10		0.736	0.733	1.10	25.5	0.043	0.058
12-BF-4-20-11		0.455	0.454	0.99	14.2	0.070	0.056
-12		0.733	0.730	1.06	25.9	0.041	0.058
-13		0.837	0.834	1.01	2919	0.034	0.059

PARAMETER SUMMARY SHEET - continued:

Run No.	Valve Opening	σ	K	Dynamic Pressure	Mean Pressure	Dynamic Pressure / Mean Pressure	$C_d = \frac{Q}{A\sqrt{2gh}}$
12-BF-4-20-14	20%	0.912	0.978	0.99	33.8	0.029	0.059
-15		1.157	1.155	0.530	38.2	0.014	0.058
-16		1.357	1.354	0.370	42.2	0.009	0.058
-17		1.763	1.758	0.300	48.8	0.006	0.059
-18		2.276	2.269	0.300	55.2	0.005	0.058
-19		2.596	2.586	0.250	58.1	0.004	0.058
12-BF-5-35-1	35%	.719	.709	1.32	20.50	0.064	0.115
-2		.883	.872	1.13	26.15	0.043	0.114
-3		1.050	1.037	1.17	30.95	0.038	0.111
-4		1.235	1.220	1.17	36.00	0.033	0.114
-5		1.402	1.385	0.80	38.80	0.021	0.115
-6		1.569	1.548	0.66	41.90	0.061	0.115
-7		1.762	1.741	0.51	45.00	0.011	0.115
-8		1.894	1.871	0.50	47.00	0.011	0.114
-9		2.101	2.074	0.47	49.30	0.010	0.115
-10		2.233	2.200	0.52	51.00	0.010	0.114
-11		2.391	2.358	0.50	53.00	0.009	0.114
-12		2.892	2.857	0.50	57.20	0.009	0.114
-13		.551	.544	1.13	14.40	0.078	0.115
-14		.446	.440	1.34	5.50	0.244	0.125
-15		.317	.313	1.37	1.65	0.830	0.116

PARAMETER SUMMARY SHEET - continued:

Run No.	Valve Opening	σ	K	Dynamic Pressure	Mean Pressure	Dynamic Pressure / Mean Pressure	$C_d = \frac{Q}{A\sqrt{2gh}}$
12-BF-6-50-1	50%	.889	0.845	1.84	15.05	.122	0.237
-2		.970	0.925	1.78	19.50	.091	0.228
-3		1.096	1.045	1.68	22.55	.075	0.229
-4		1.440	1.373	1.49	30.55	.049	0.229
-5		1.675	1.599	1.364	34.80	.039	0.227
-6		1.986	1.985	1.144	39.20	.029	0.227
-7		2.279	2.174	1.210	42.80	.028	0.228
-8		6.099	5.810	1.276	65.10	.020	0.230
-9		3.179	3.032	.99	51.0	.019	0.229
-10		5.775	5.508				0.228
-11		.505	0.482	1.54	100.0	.015	0.232
12-BG-6-50-1	50%	.821	0.782	1.81	15.05	.120	0.230
-2		.975	0.930	1.94	19.50	.099	0.228
-3		1.096	1.045	1.78	22.90	.078	0.229
-4		1.447	1.381	1.45	30.40	.048	0.228
-5		1.684	1.607	1.276	35.10	.036	0.226
-6		1.986	1.895	1.21	39.00	.031	0.228
-7		2.279	2.175	1.10	43.10	.026	0.226
-8		6.099	5.810	.704	65.10	.011	0.230
-9		3.179	3.032	.924	51.70	.018	0.228
-10		.505	0.482				0.230

PARAMETER SUMMARY SHEET - continued:

Run No.	Valve Opening	σ	K	Dynamic Pressure	Mean Pressure	Dynamic Pressure / Mean Pressure	$C_d = \frac{Q}{A\sqrt{2gh}}$
12-BH-6-50-1	50%	1.184	1.096	1.45	23.0	.063	
-2		1.393	1.338	1.39	27.70	.050	
-3		1.587	1.477	1.16	30.90	.038	
-4		2.101	1.957	No Tape Sheet			
-5		2.546	2.367	1.078	43.20	.025	
-6		5.400	5.027	1.320	62.0	.021	
12-BH-9-50-7		.696	0.648	1.94	11.50	.169	
12-BF-9-70-1	50%	1.538	1.295	1.62	18.75	.086	0.460
-2		1.944	1.635	1.78	25.0	.071	0.456
-3		2.738	2.311	1.68	32.05	.052	0.449
-4		3.252	2.744	1.39	37.00	.038	0.449
-5		3.783	3.179	1.166	40.8	.029	0.455
-6		4.409	3.712	1.188	44.70	.027	0.451
-7		5.509	4.639	.99	51.00	.019	0.450
-8		7.717	6.472	.704	58.50	.012	0.456
-9		2.508	2.137				0.435
12-BF-10-20-1	20%	.275	.274	1.035	4.05	.256	0.052
-2		.457	.456	1.086	14.50	.075	0.053
-3		.598	.596	1.202	21.20	.057	0.053
-4		.707	.705	1.086	25.70	.042	0.054
-5		.938	.936	1.069	30.00	.036	0.054

PARAMETER SUMMARY SHEET - continued:

Run No.	Valve Opening	σ	K	Dynamic Pressure	Mean Pressure	$\frac{\text{Dynamic Pressure}}{\text{Mean Pressure}}$	$C_d = \frac{Q}{A\sqrt{2gh}}$
12-BF-10-20-6	20%	1.088	1.085	.919	36.90	.025	0.055
-7		1.387	1.383	.460	42.80	.011	0.055
-8		1.660	1.656	.400	87.80	.005	0.054
-9		1.985	1.979	.375	51.70	.007	0.054
-10		2.208	2.200	.350	54.30	.006	0.054
-11		2.422	2.413	.350	56.40	.006	0.052
12-BF-11-50-7	50%	2.01	1.972	.836	50.7	.016	0.145
-8		2.252	2.206	.836	52.4	.016	0.147
-9		2.682	2.631	.836	56.2	.015	0.148
-10		5.063	4.969	.684	68.9	.010	0.148
-11		1.082	1.061	1.499	33.3	.045	0.147
-12		1.287	1.262	1.432	38.3	.037	0.144
-13		1.607	1.576	1.144	43.8	.026	0.144
-14		.738	0.724	1.832	24.3	.075	0.147
-15		.526	0.515	1.765	15.8	.112	0.147
-16		.416	0.408	1.777	11.7	.152	0.145

Appendix B Plots

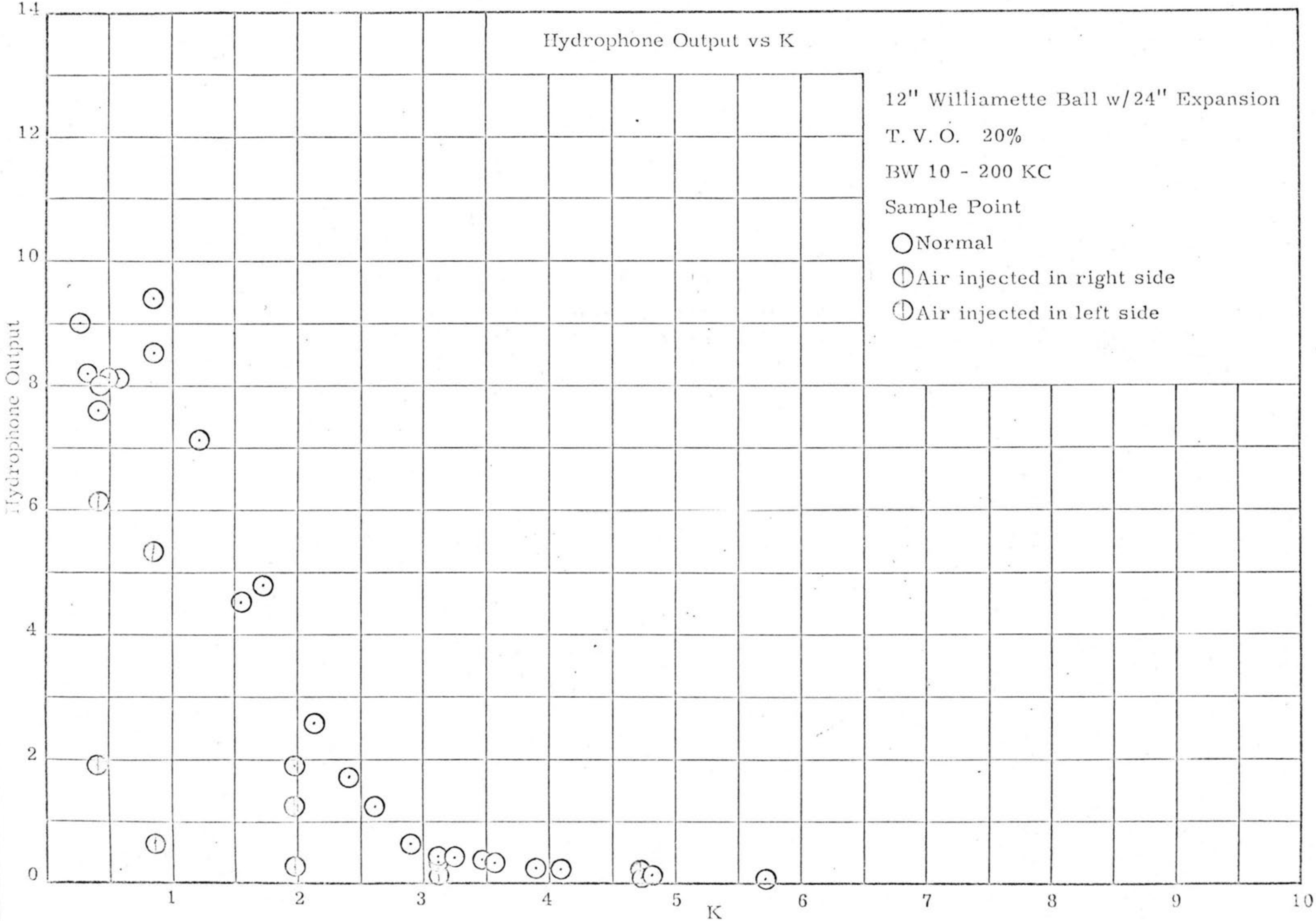
1) Hydrophone Output vs K (20 and 50 percent opening - air injection, water bypass, and orifice twenty four-inches upstream from test valve).

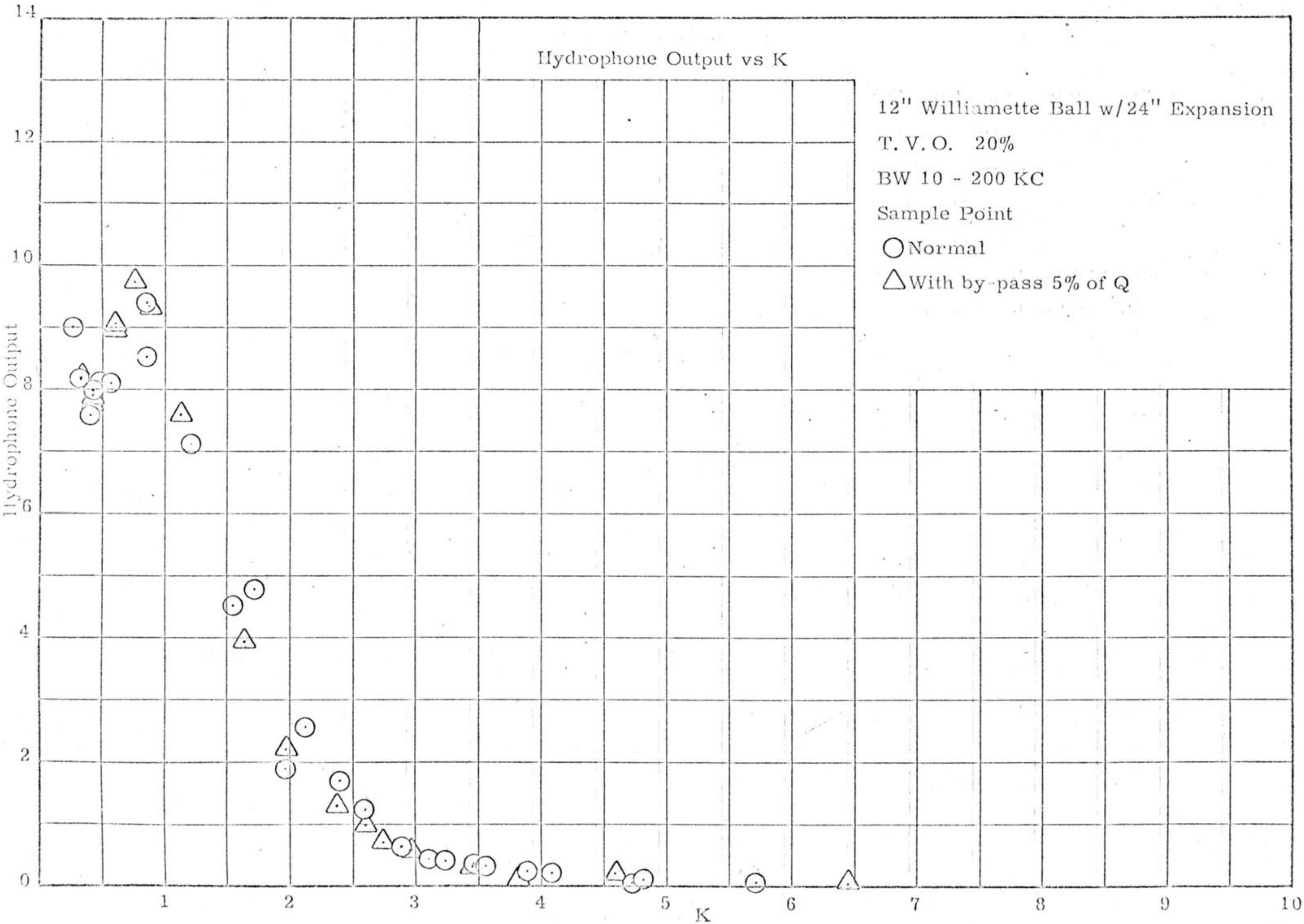
2) Hydrophone Output vs K (20, 35, 50, and 70 percent opening).

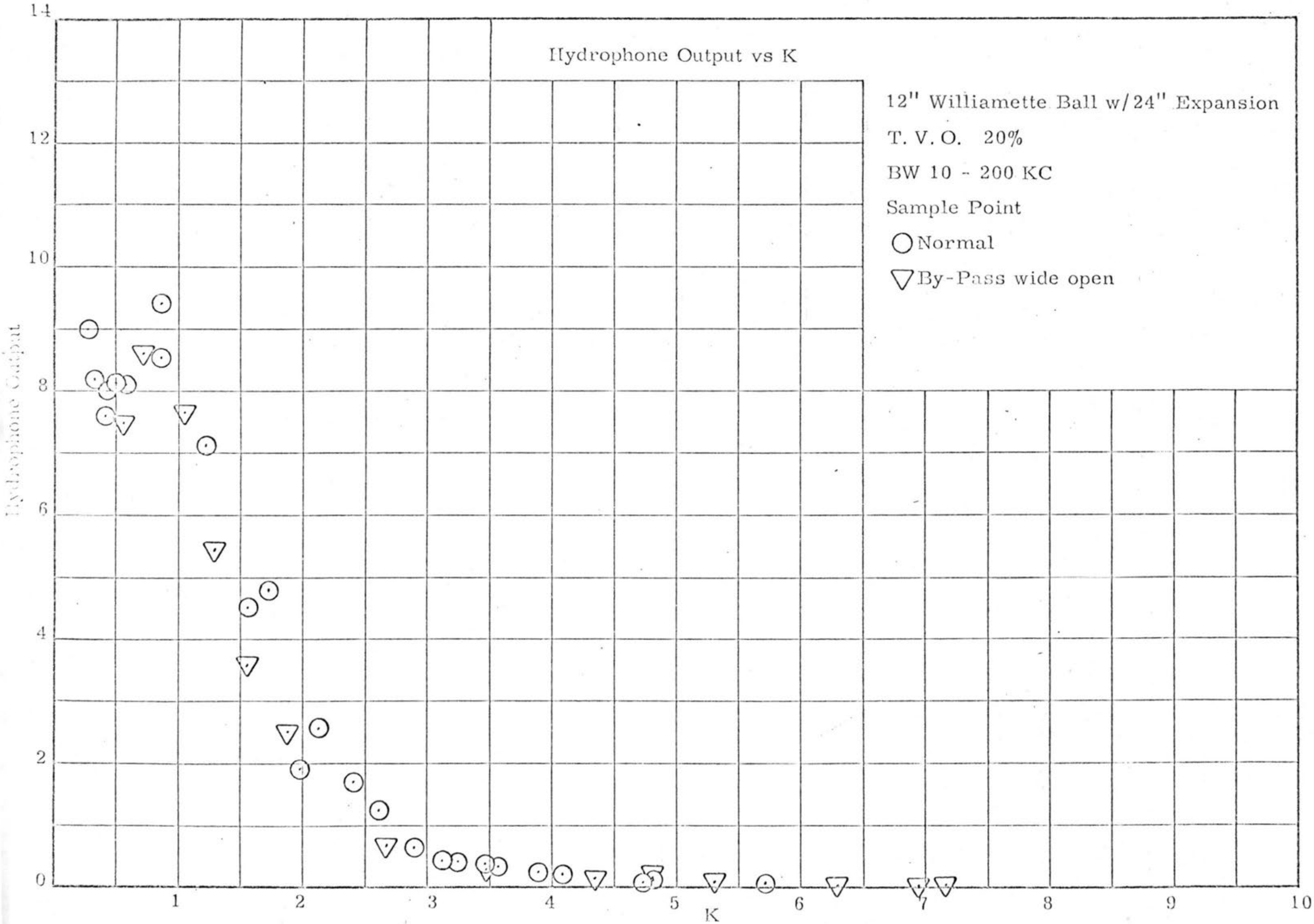
3) Vertical Vibration vs K (20 and 50 percent opening - air injection, water bypass, and orifice twenty four-inches upstream from test valve).

4) Vertical Vibration vs K (20, 35, 50 and 70 percent opening).

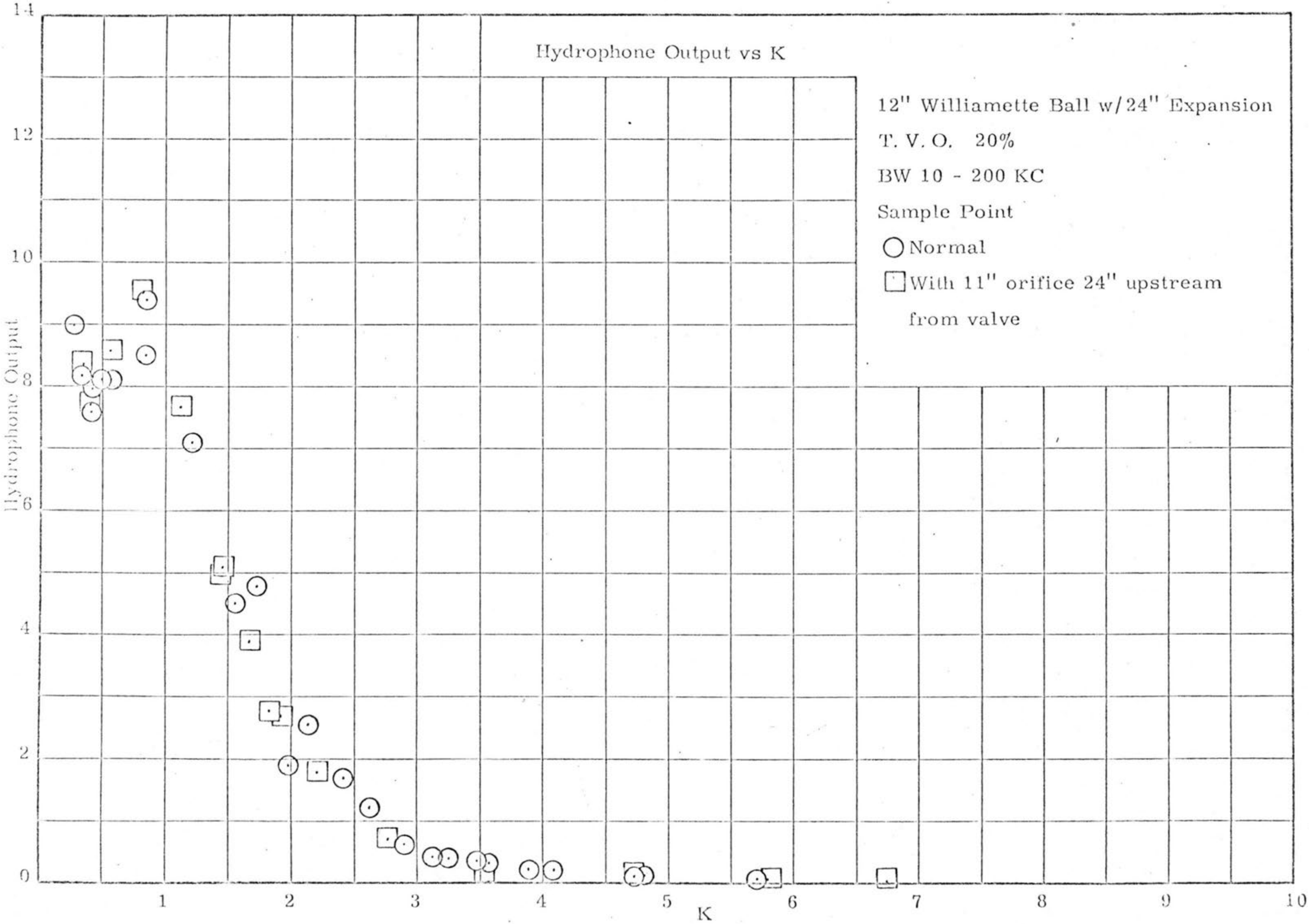
5) ΔH vs Q vs H_D vs cavitating or non-cavitating conditions.


Hydrophone Output vs K
12" Williamette Ball w/24" Expansion
T. V. O. 20%
BW 10 - 200 KC
Sample Point
Normal
Air injected in right side
Air injected in left side
Hydrophone Output
K
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10

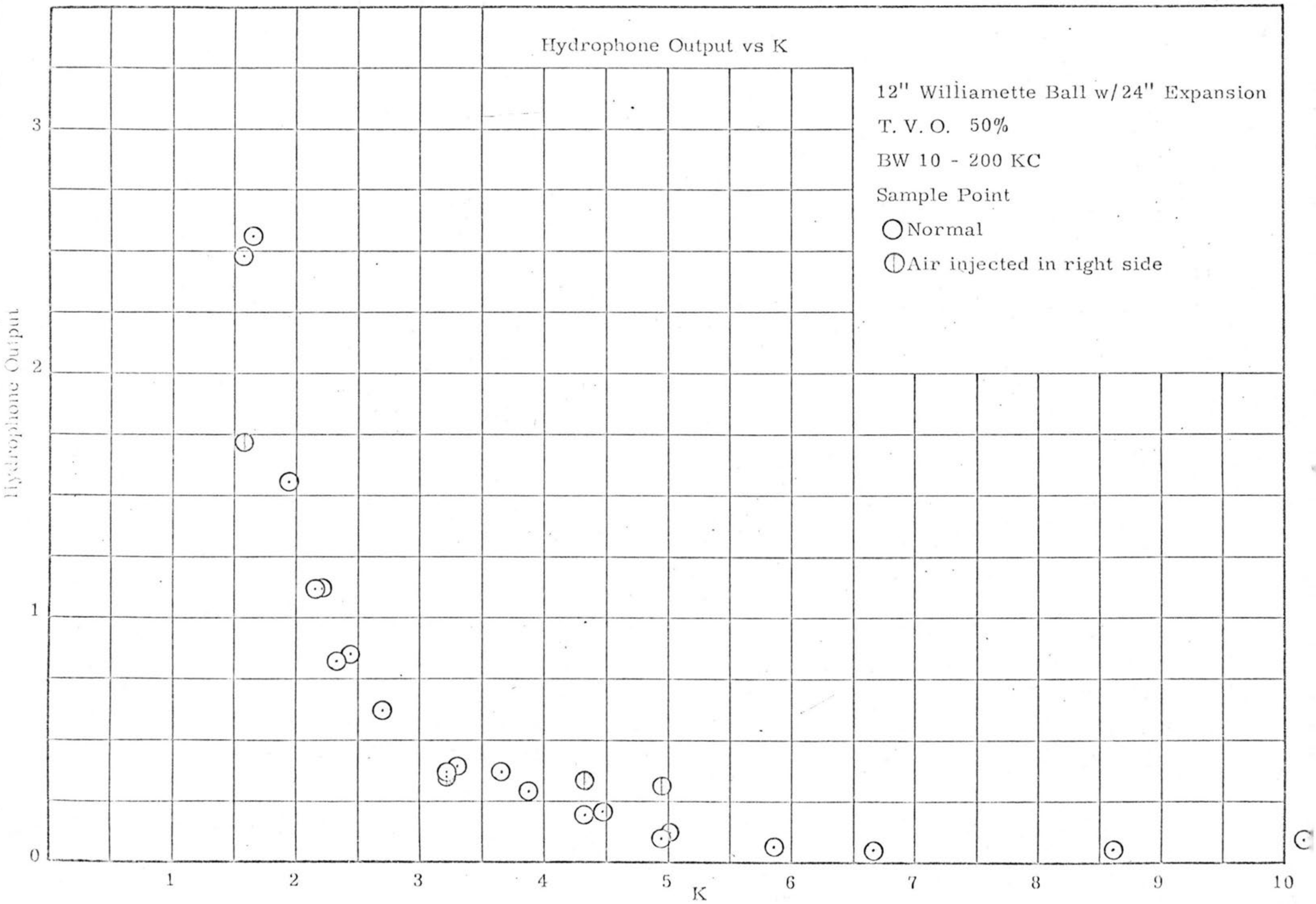

Hydrophone Output vs K
12" Williamette Ball w/24" Expansion
T. V. O. 20%
BW 10 - 200 KC
Sample Point
Normal
With by-pass 5% of Q
Hydrophone Output
K
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10

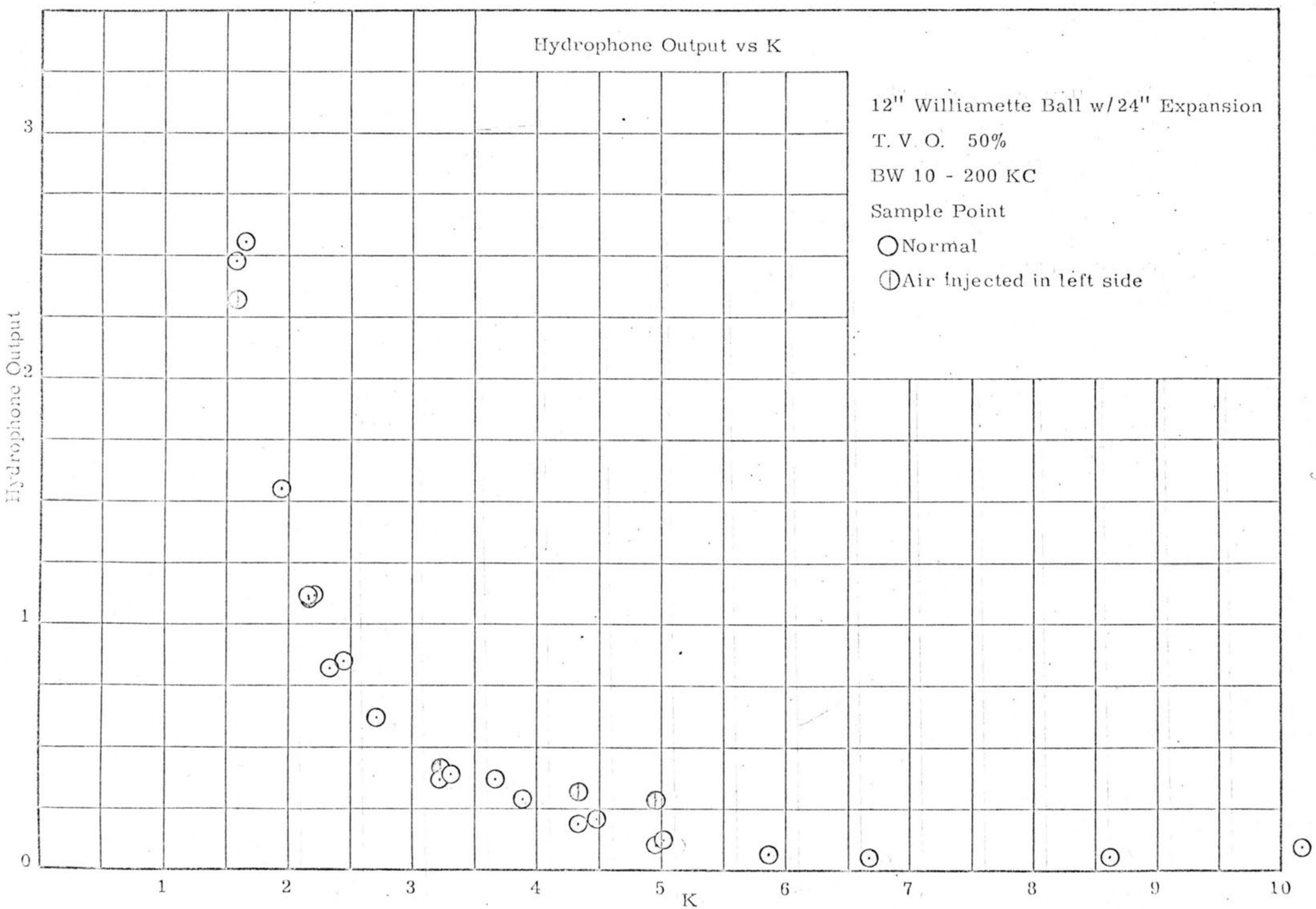


Hydrophone Output vs K
12" Williamette Ball w/24" Expansion
T. V. O. 20%
BW 10 - 200 KC
Sample Point
Normal
By-Pass wide open
Hydrophone Output
K
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10

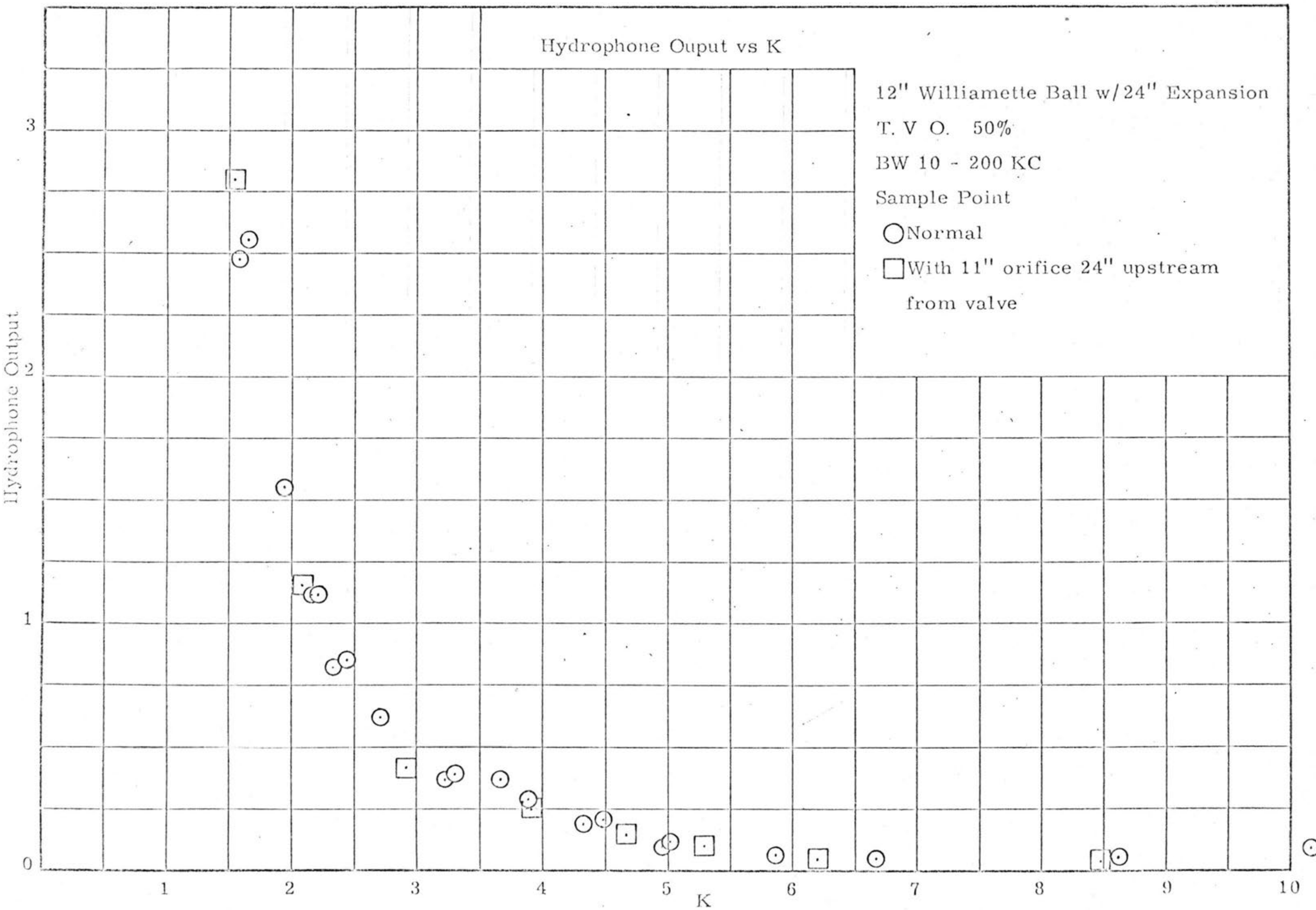


Hydrophone Output vs K
12" Williamette Ball w/24" Expansion
T. V. O. 20%
BW 10 - 200 KC
Sample Point
Normal
With 11" orifice 24" upstream from valve
Hydrophone Output
K
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10

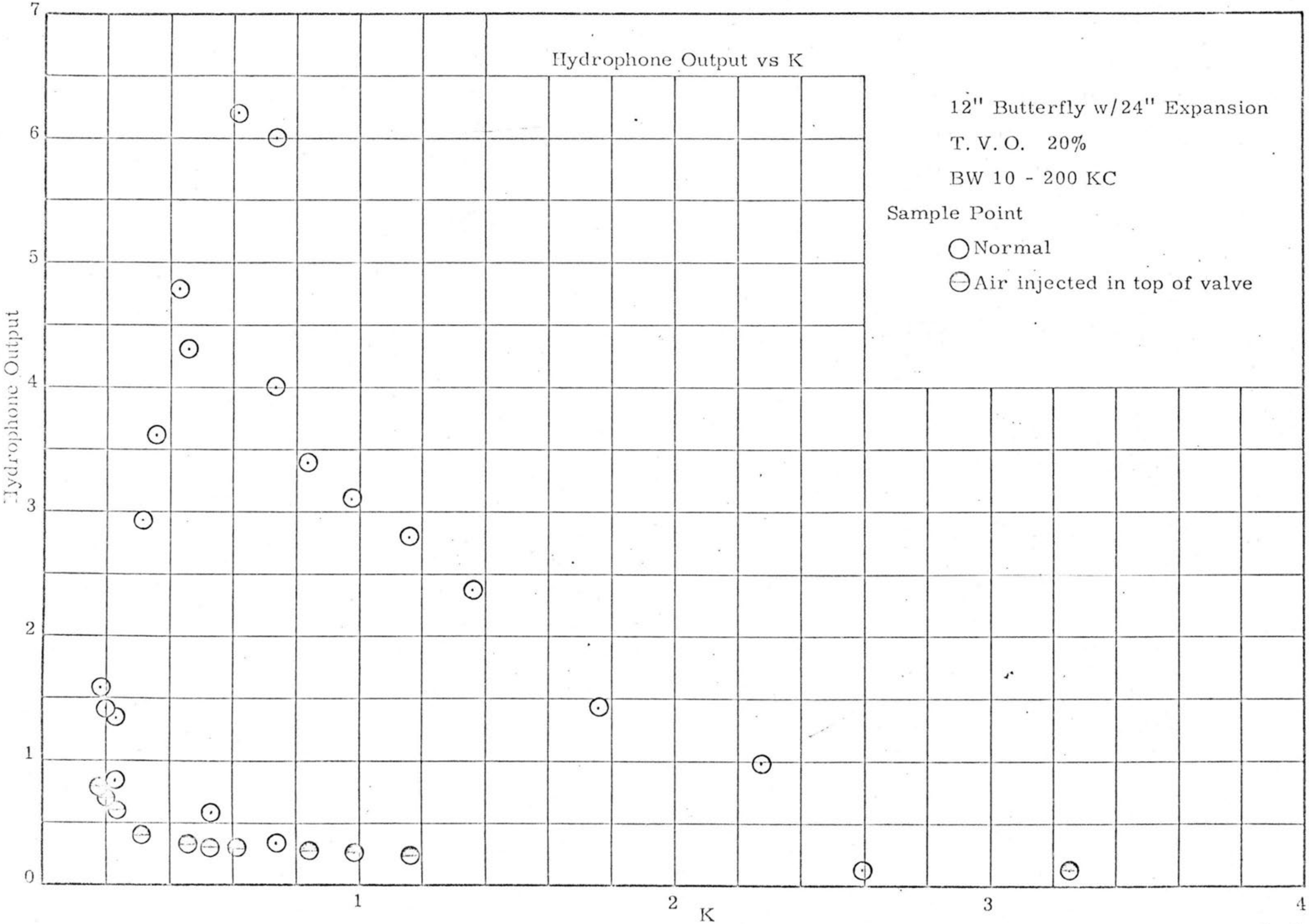

Hydrophone Output vs K
12" Williamette Ball w/24" Expansion
T. V. O. 50%
BW 10 - 200 KC
Sample Point
Normal
Air injected in right side
Hydrophone Output
0
1
2
3
K
1
2
3
4
5
6
7
8
9
10



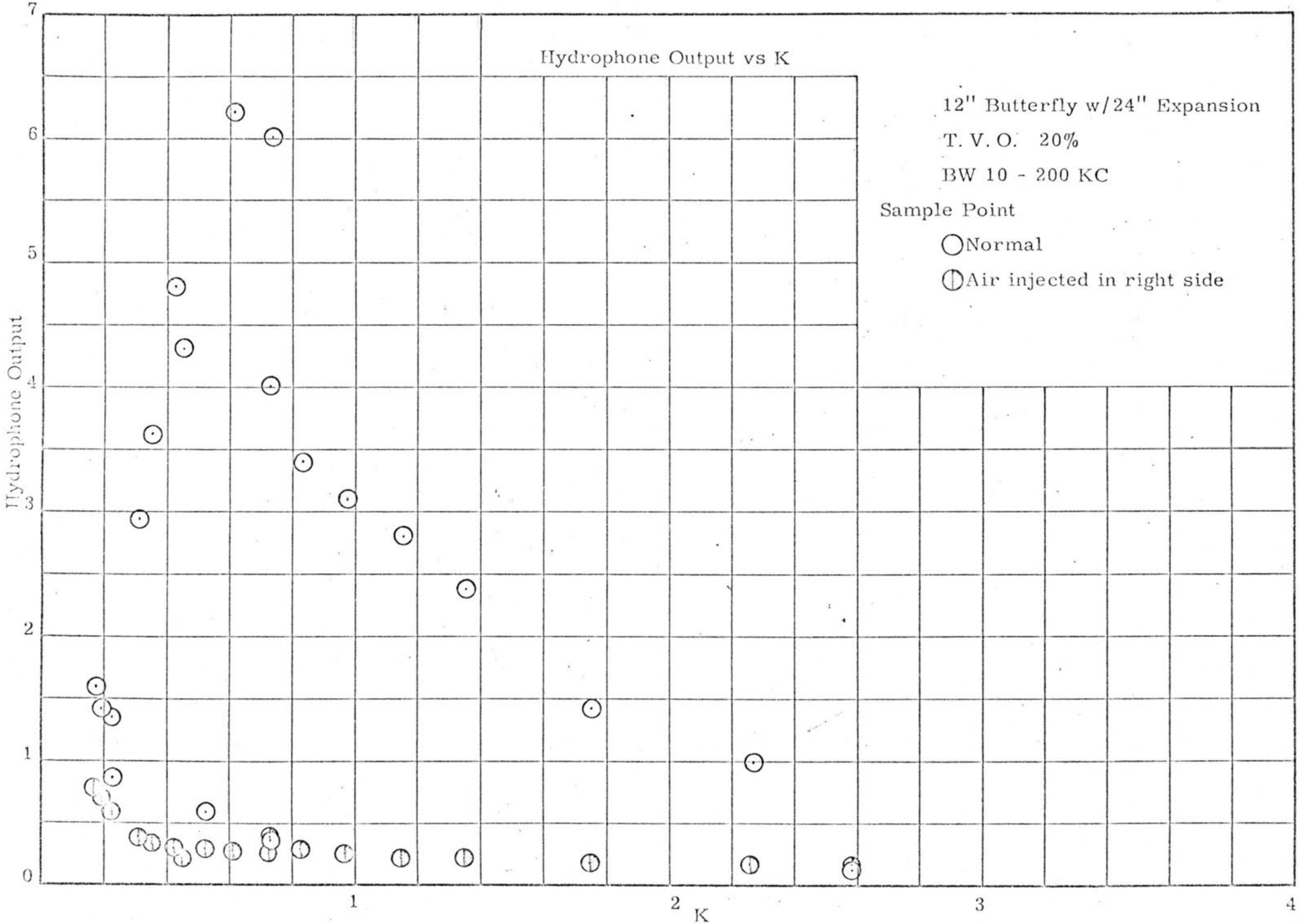
Hydrophone Output vs K
12" Williamette Ball w/24" Expansion
T. V. O. 50%
BW 10 - 200 KC
Sample Point
Normal
Air injected in left side
Hydrophone Output
3
2
1
0
1
2
3
4
5
6
7
8
9
10
K



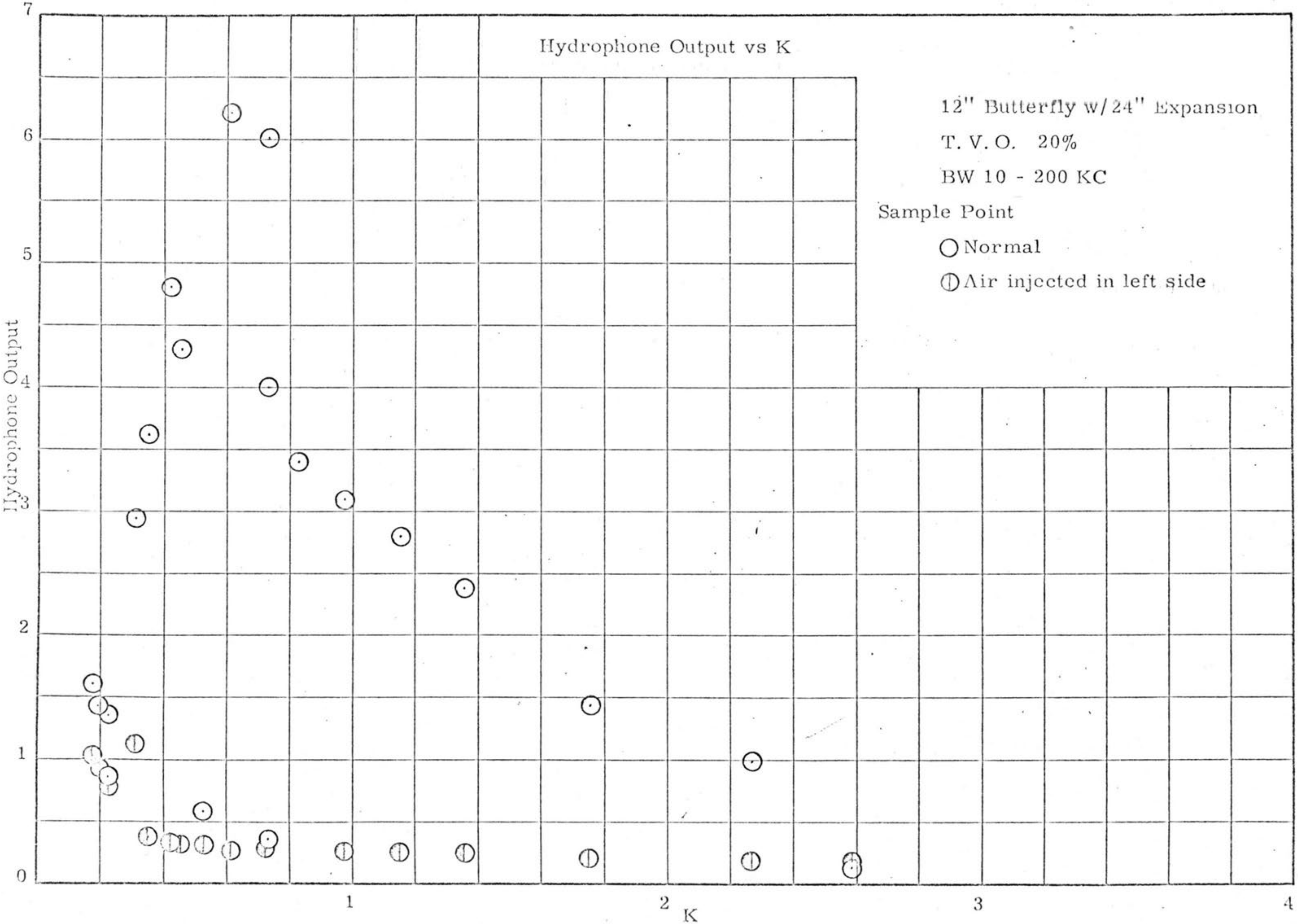
Hydrophone Ouput vs K
12" Williamette Ball w/24" Expansion
T. V O. 50%
BW 10 - 200 KC
Sample Point
Normal
With 11" orifice 24" upstream from valve
Hydrophone Output
K
0
1
2
3
1
2
3
4
5
6
7
8
9
10

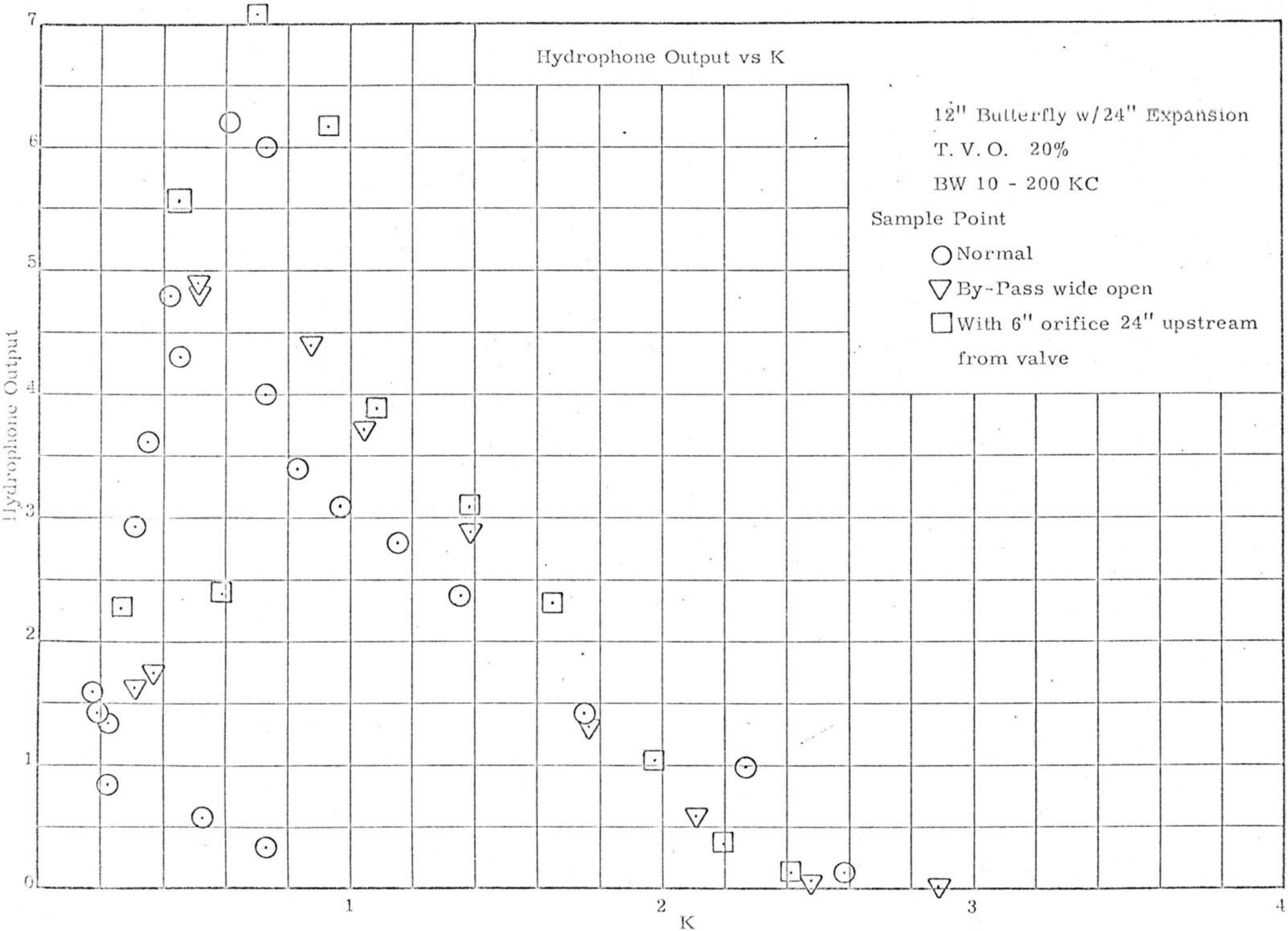


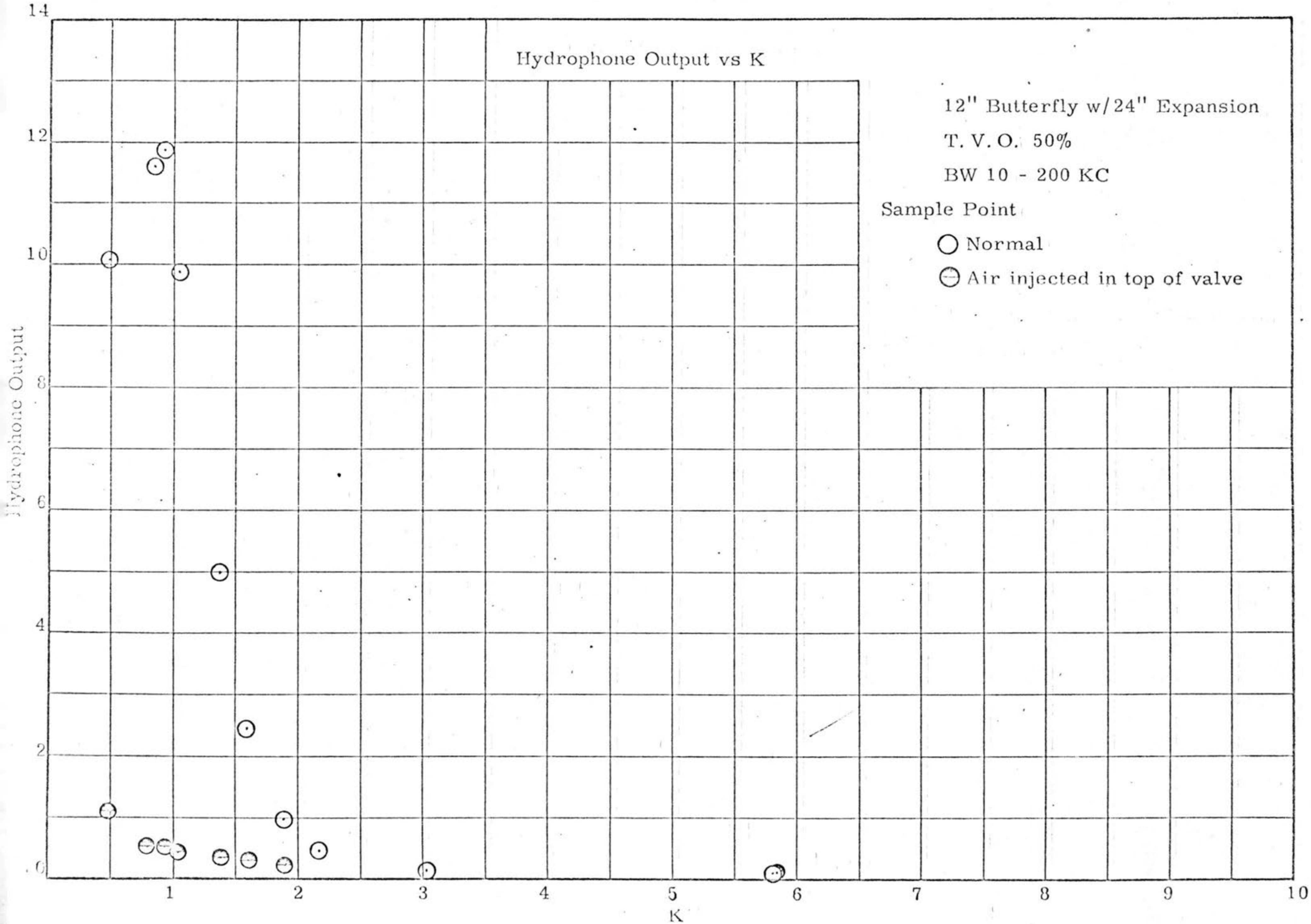
Hydrophone Output vs K
12" Butterfly w/24" Expansion
T. V. O. 20%
BW 10 - 200 KC
Sample Point
Normal
Air injected in top of valve
Hydrophone Output
K
0
1
2
3
4
5
6
7
1
2
3
4

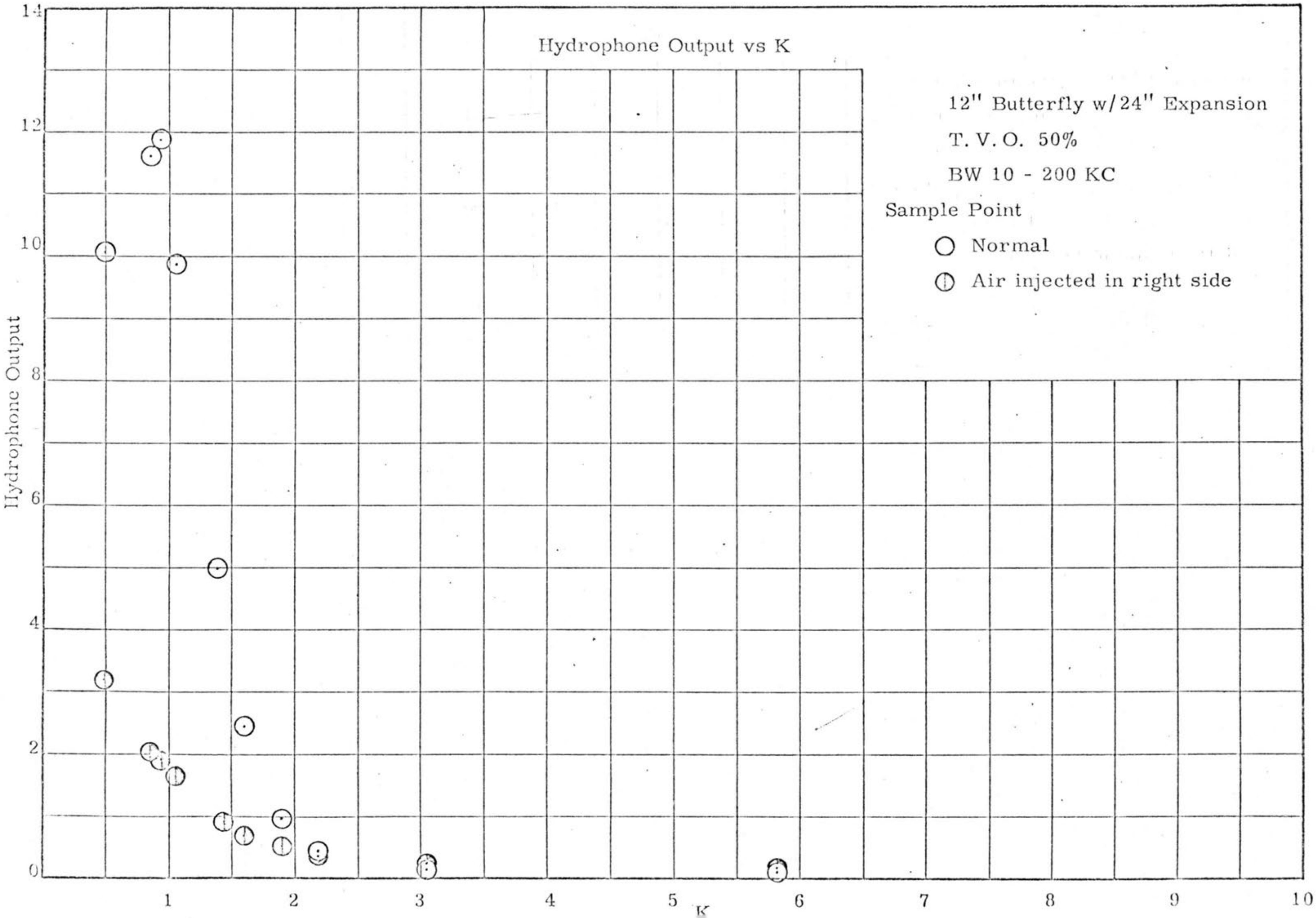


Hydrophone Output vs K
12" Butterfly w/24" Expansion
T. V. O. 20%
BW 10 - 200 KC
Sample Point
Normal
Air injected in right side
Hydrophone Output
K
0
1
2
3
4
5
6
7
1
2
3
4

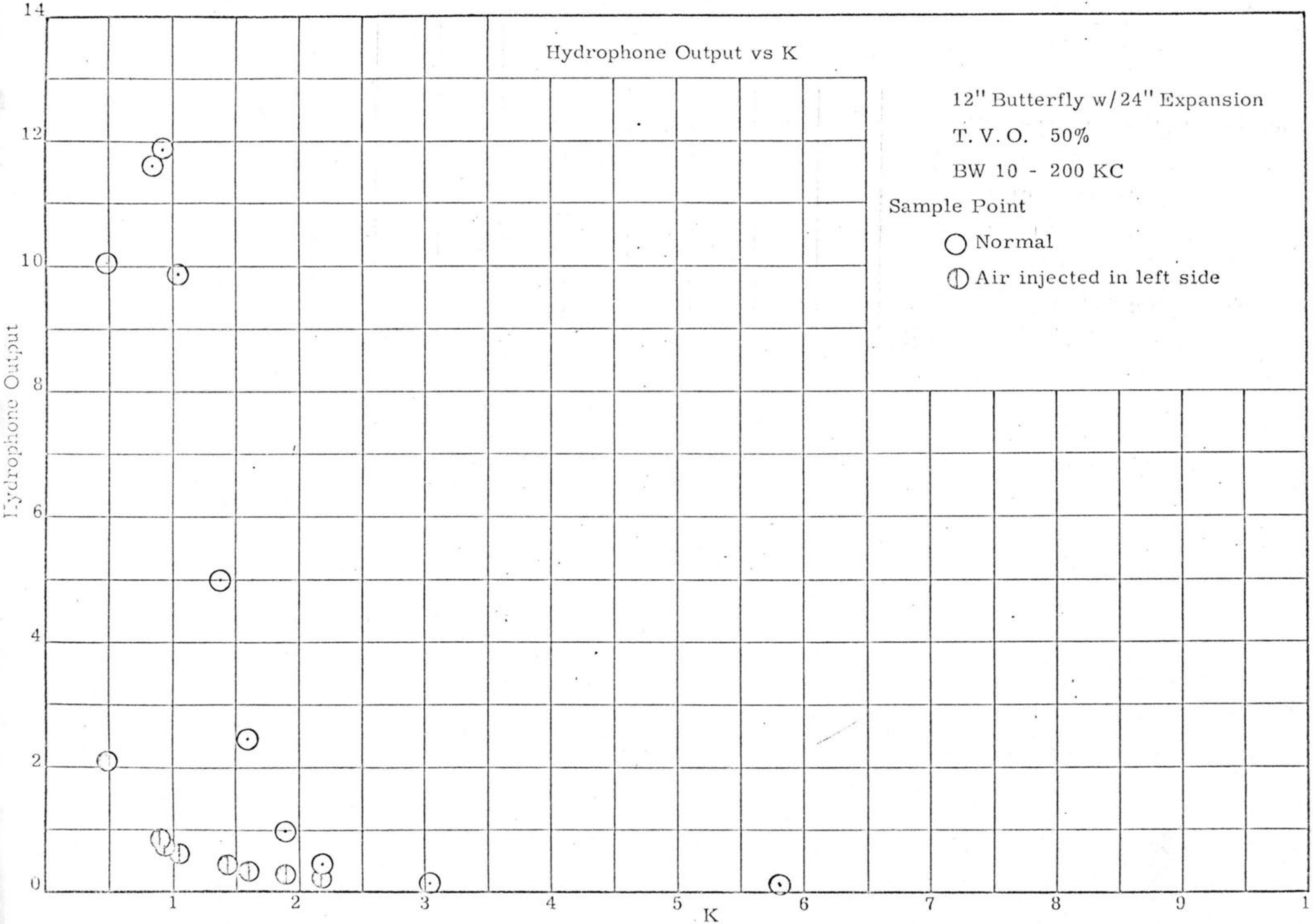

Hydrophone Output vs K
12" Butterfly w/24" Expansion
T. V. O. 20%
BW 10 - 200 KC
Sample Point
Normal
Air injected in left side
Hydrophone Output
K
0
1
2
3
4
5
6
7
1
2
3
4


Hydrophone Output vs K
12" Butterfly w/24" Expansion
T. V. O. 20%
BW 10 - 200 KC
Sample Point
Normal
By-Pass wide open
With 6" orifice 24" upstream from valve
Hydrophone Output
K
0
1
2
3
4
5
6
7
1
2
3
4


Hydrophone Output vs K
12" Butterfly w/24" Expansion
T. V. O. 50%
BW 10 - 200 KC
Sample Point
Normal
Air injected in top of valve
Hydrophone Output
K
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10



Hydrophone Output vs K
12" Butterfly w/24" Expansion
T. V. O. 50%
BW 10 - 200 KC
Sample Point
Normal
Air injected in right side
Hydrophone Output
K
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10



Hydrophone Output vs K
12" Butterfly w/24" Expansion
T. V. O. 50%
BW 10 - 200 KC
Sample Point
Normal
Air injected in left side
Hydrophone Output
K
0
2
4
6
8
10
12
14
1
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3
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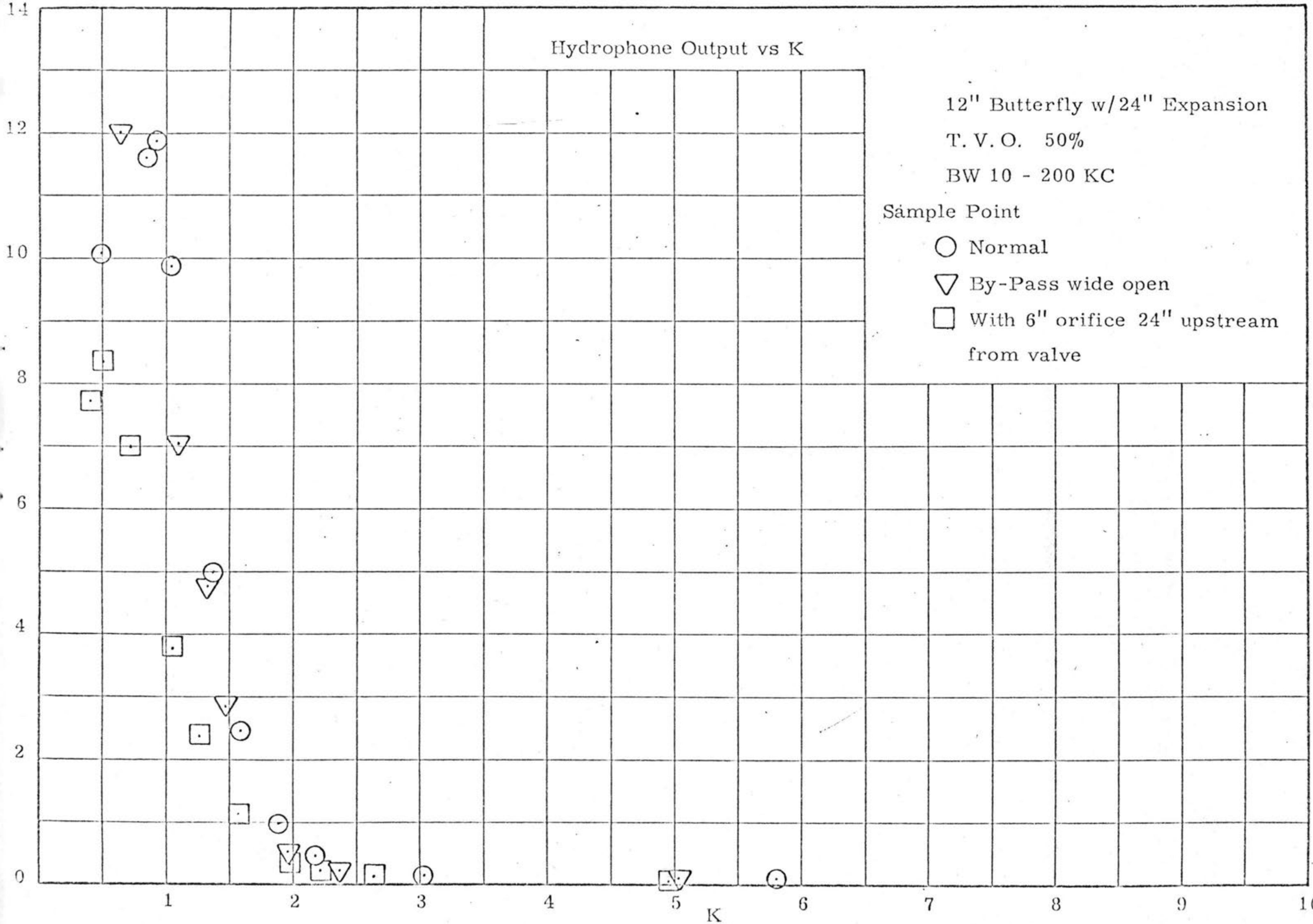
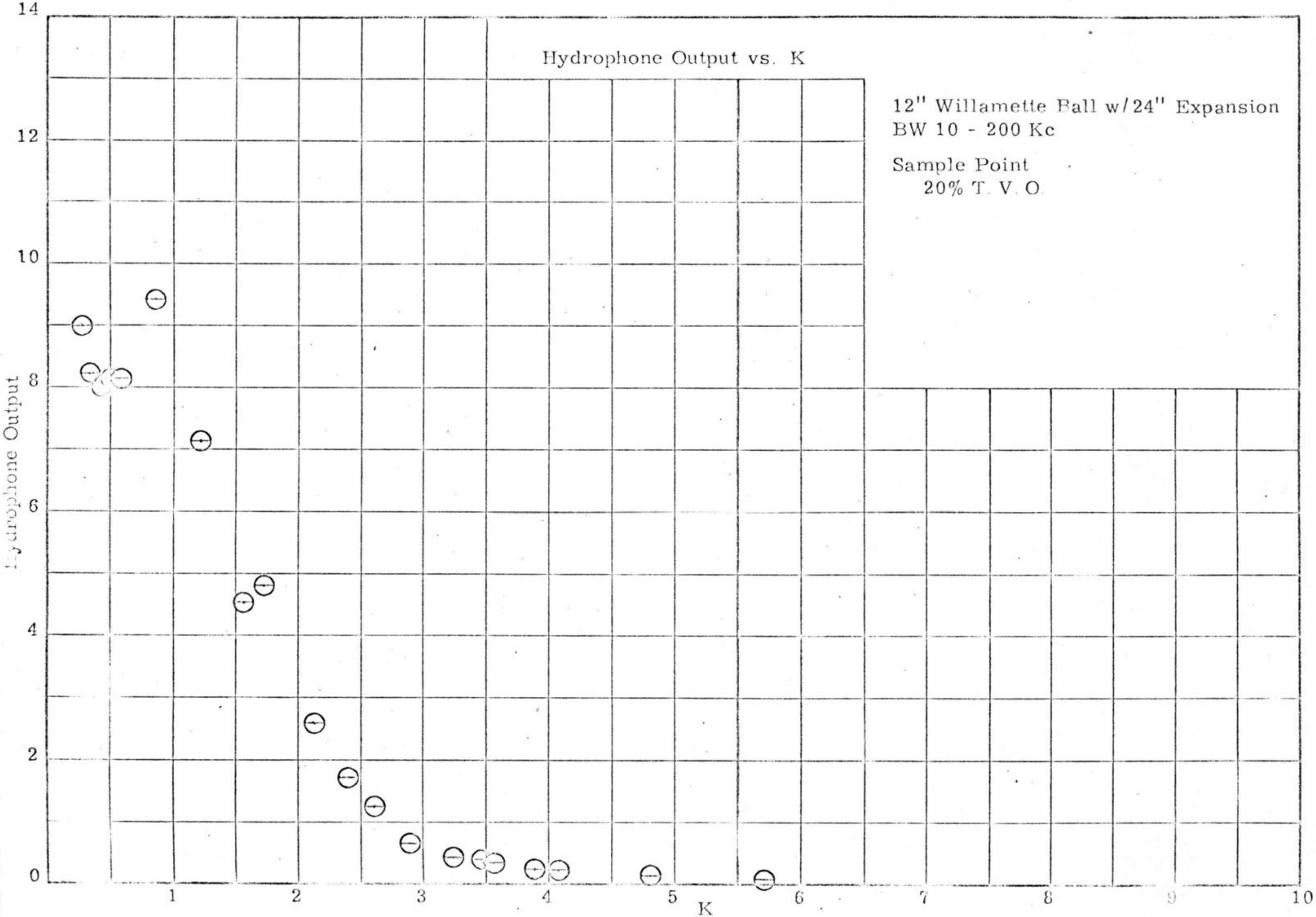
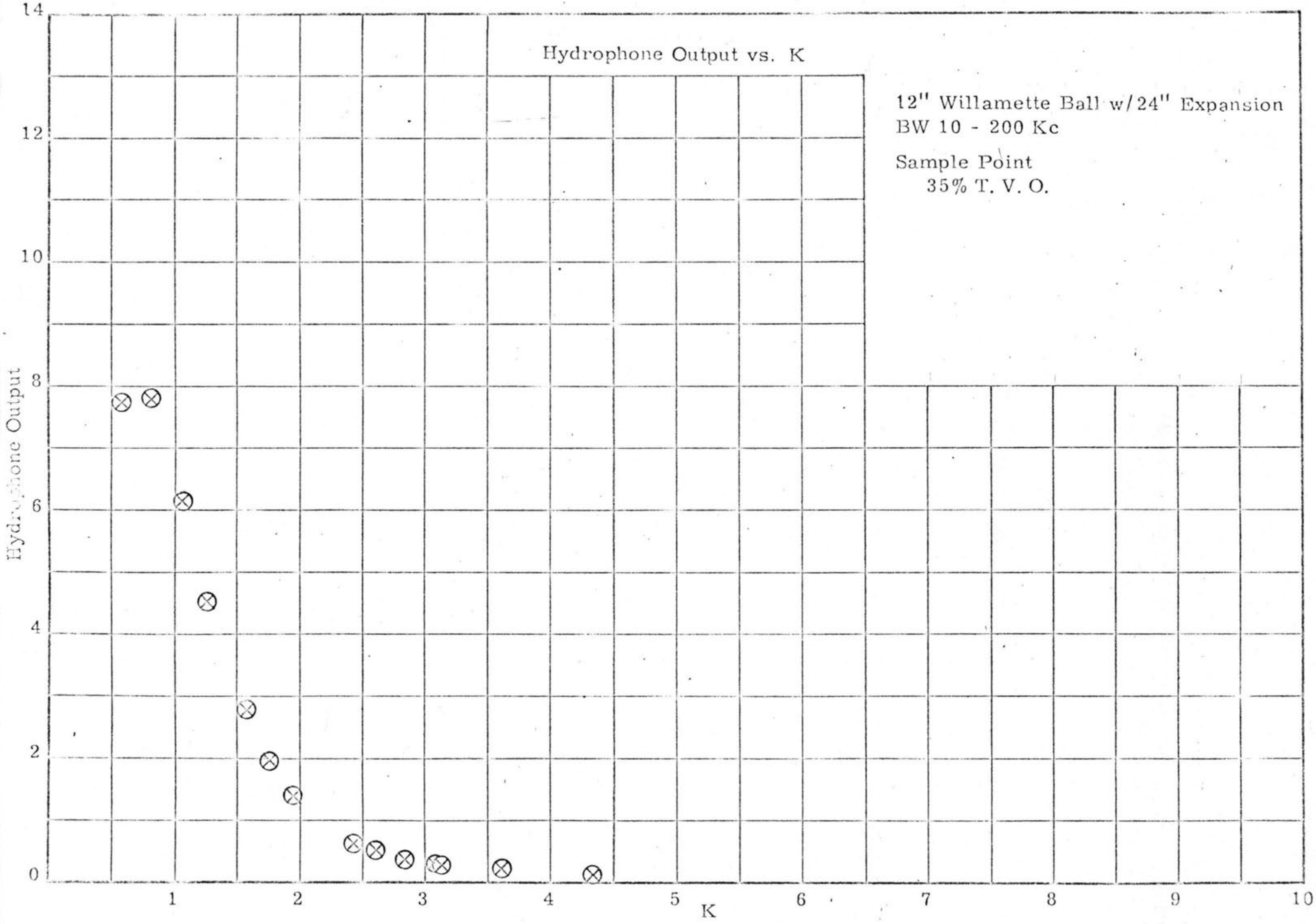
10



Hydrophone Output vs K
12" Butterfly w/24" Expansion
T. V. O. 50%
BW 10 - 200 KC
Sample Point
Normal
By-Pass wide open
With 6" orifice 24" upstream from valve
K
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10



Hydrophone Output vs. K
12" Willamette Ball w/24" Expansion
BW 10 - 200 Kc
Sample Point
20% T. V. O.
Hydrophone Output
K
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10


Hydrophone Output vs. K
12" Willamette Ball w/24" Expansion
BW 10 - 200 Kc
Sample Point
35% T. V. O.
Hydrophone Output
K
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
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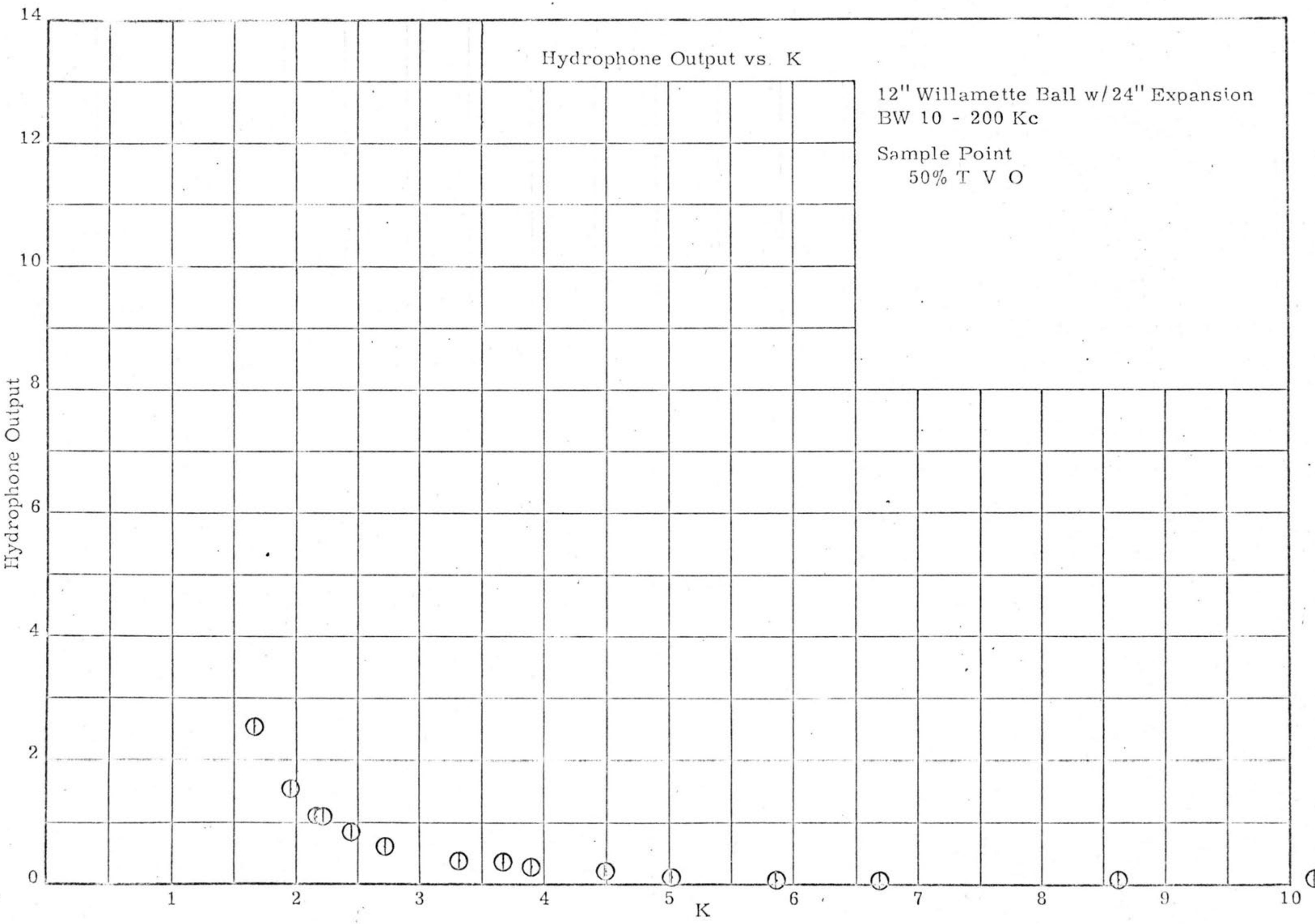
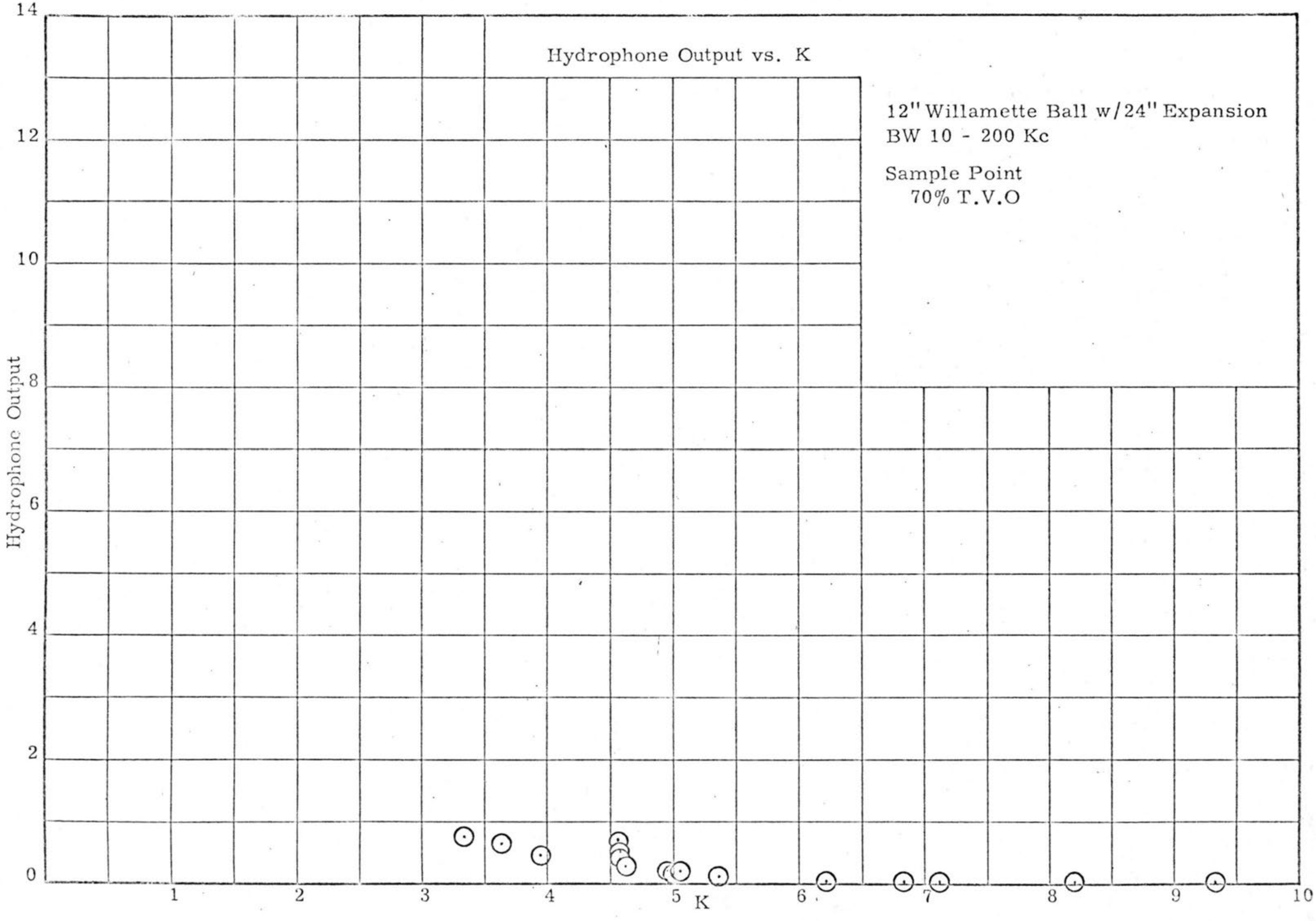
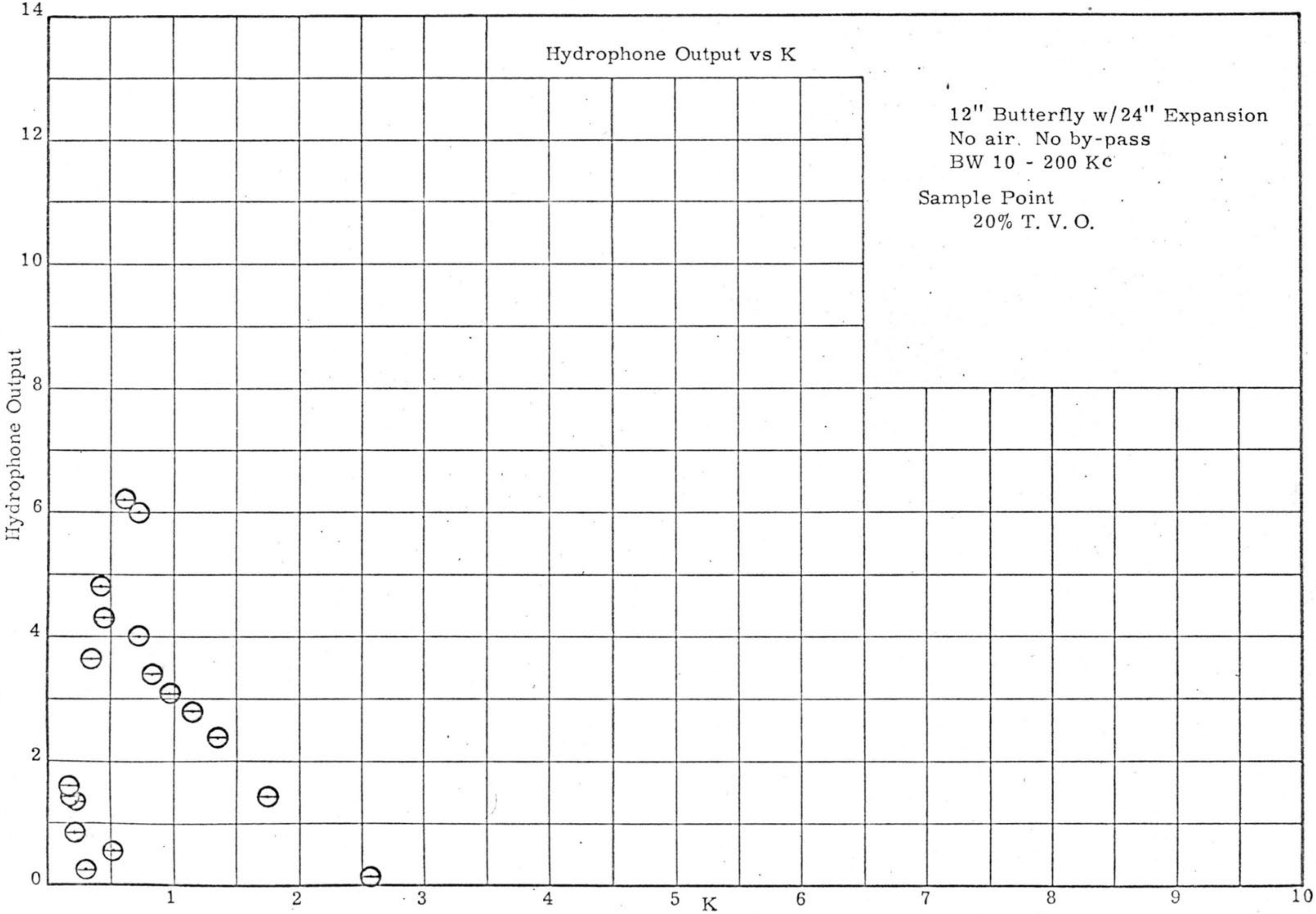
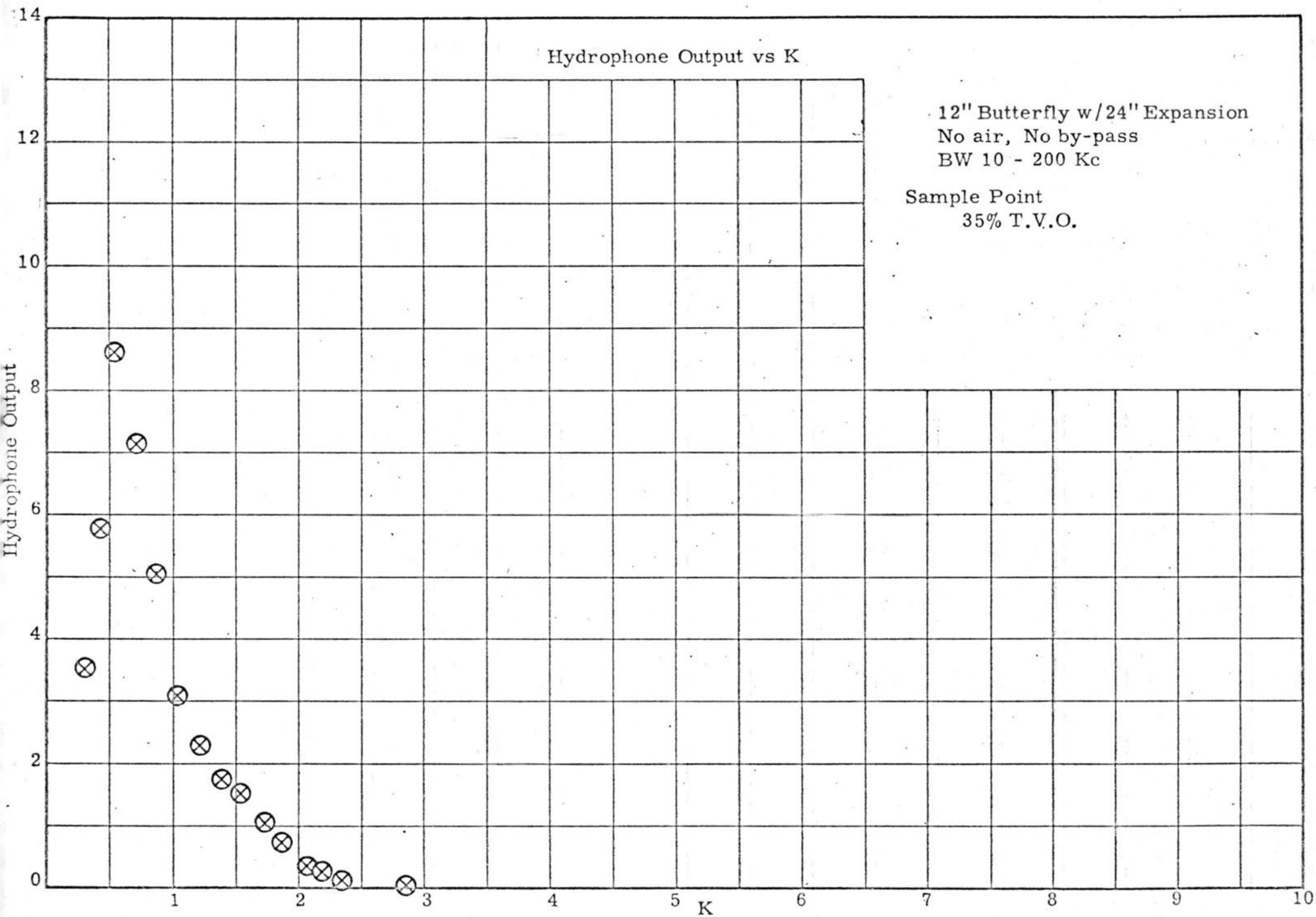
9
10

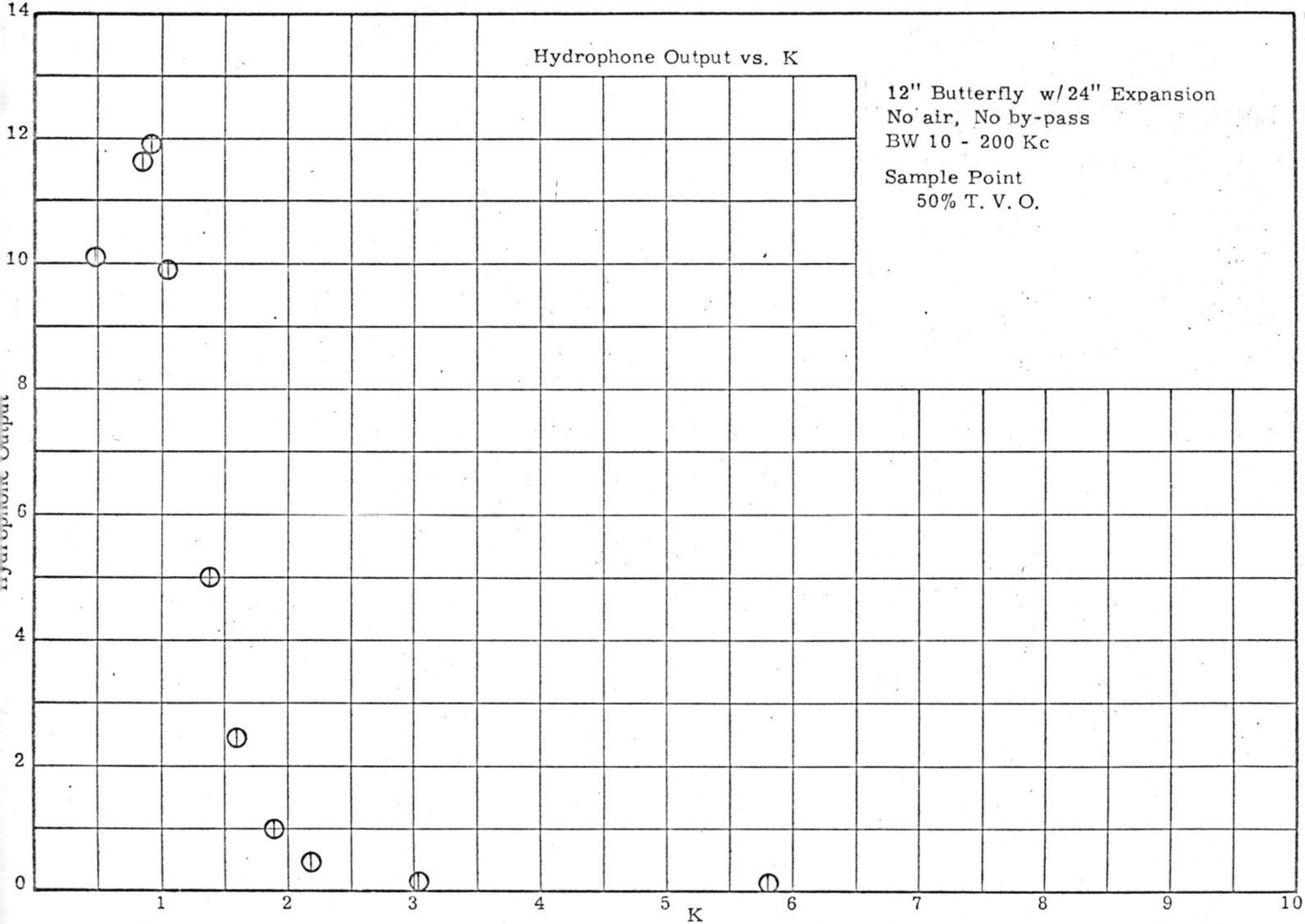

Hydrophone Output vs. K
12" Willamette Ball w/24" Expansion
BW 10 - 200 Kc
Sample Point
50% T V O
Hydrophone Output
K
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10


Hydrophone Output vs. K
12" Willamette Ball w/24" Expansion
BW 10 - 200 Kc
Sample Point
70% T.V.O
Hydrophone Output
K
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10

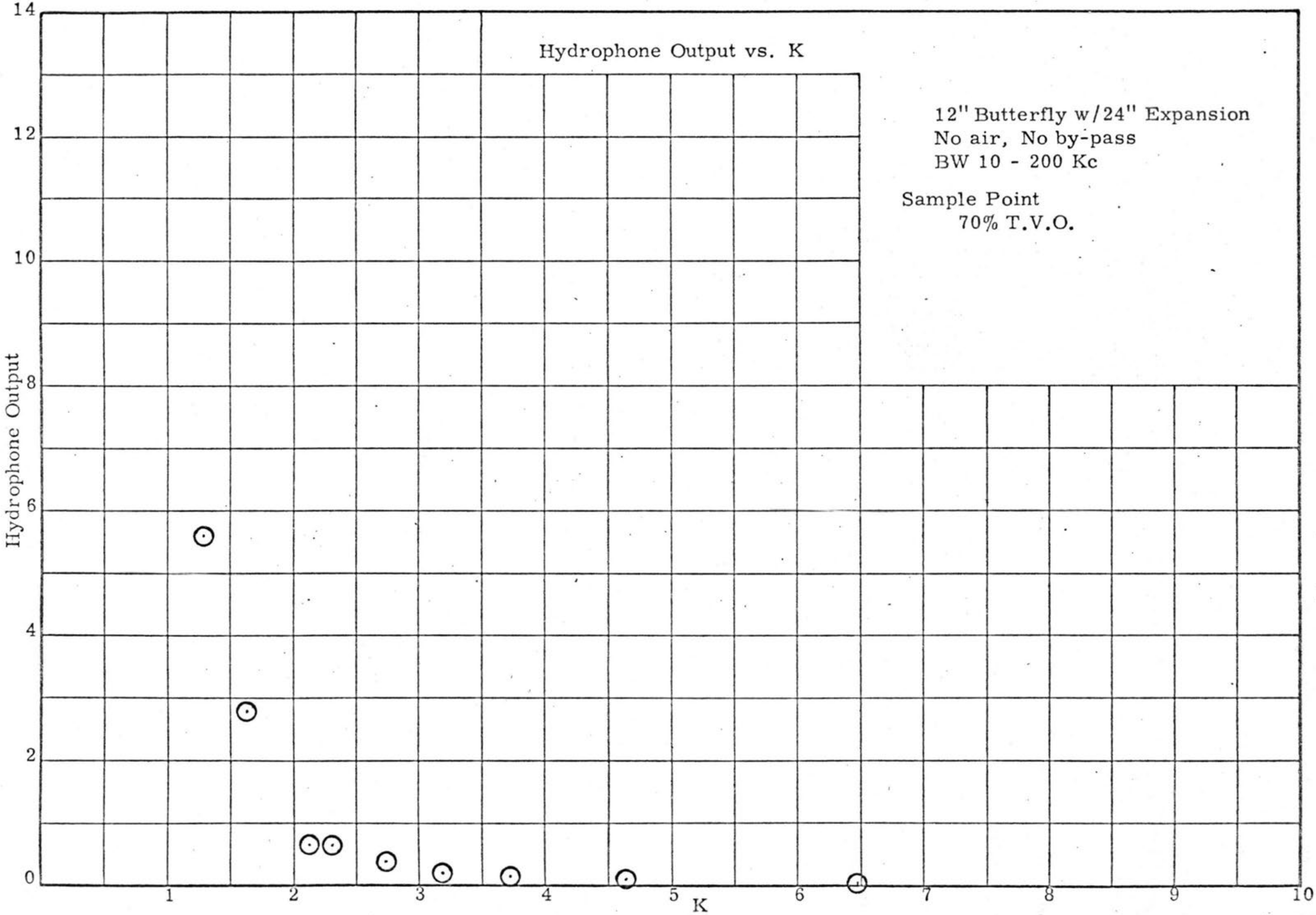


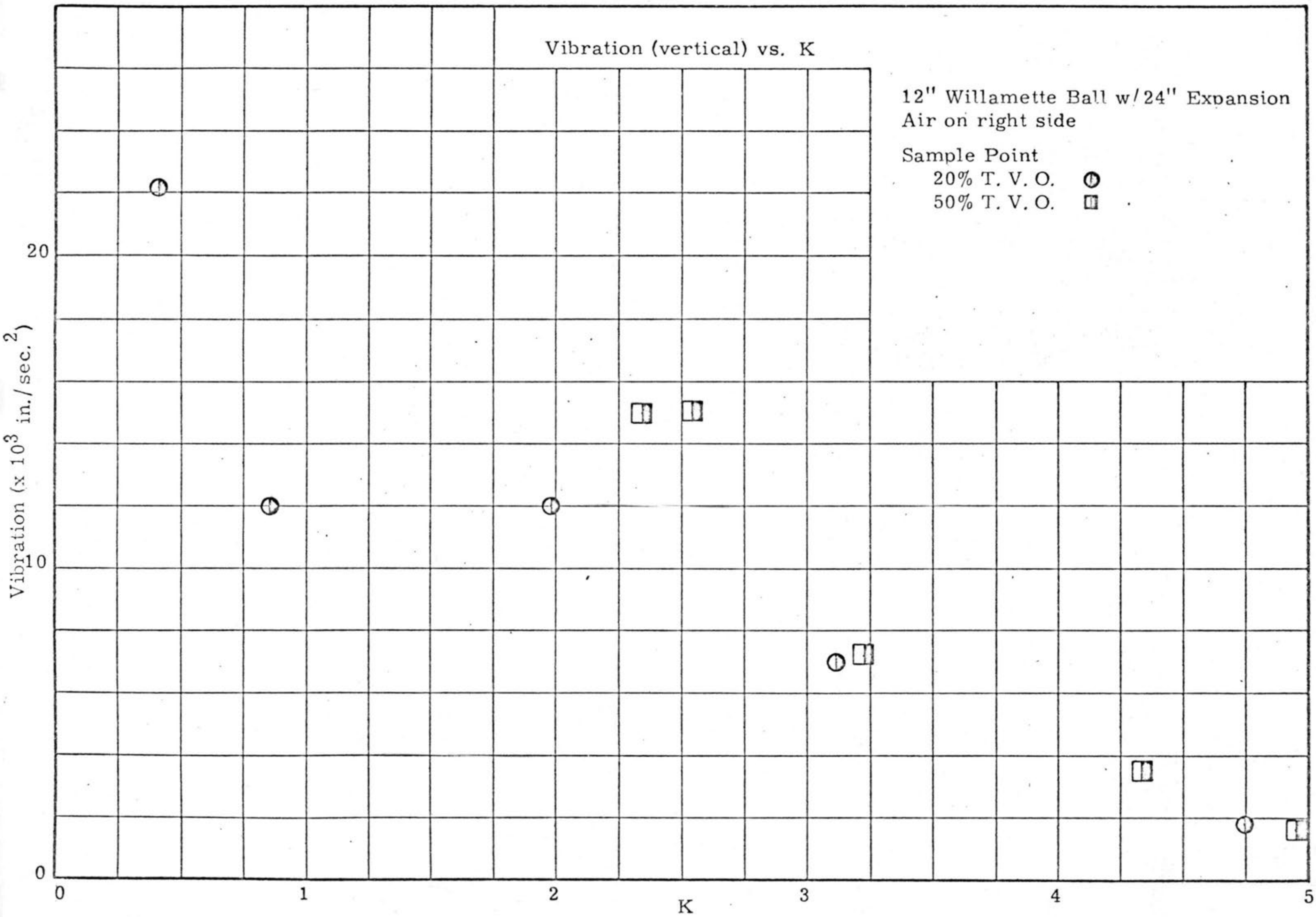
Hydrophone Output vs K
12" Butterfly w/24" Expansion
No air. No by-pass
BW 10 - 200 Kc
Sample Point
20% T. V. O.
Hydrophone Output
K
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10

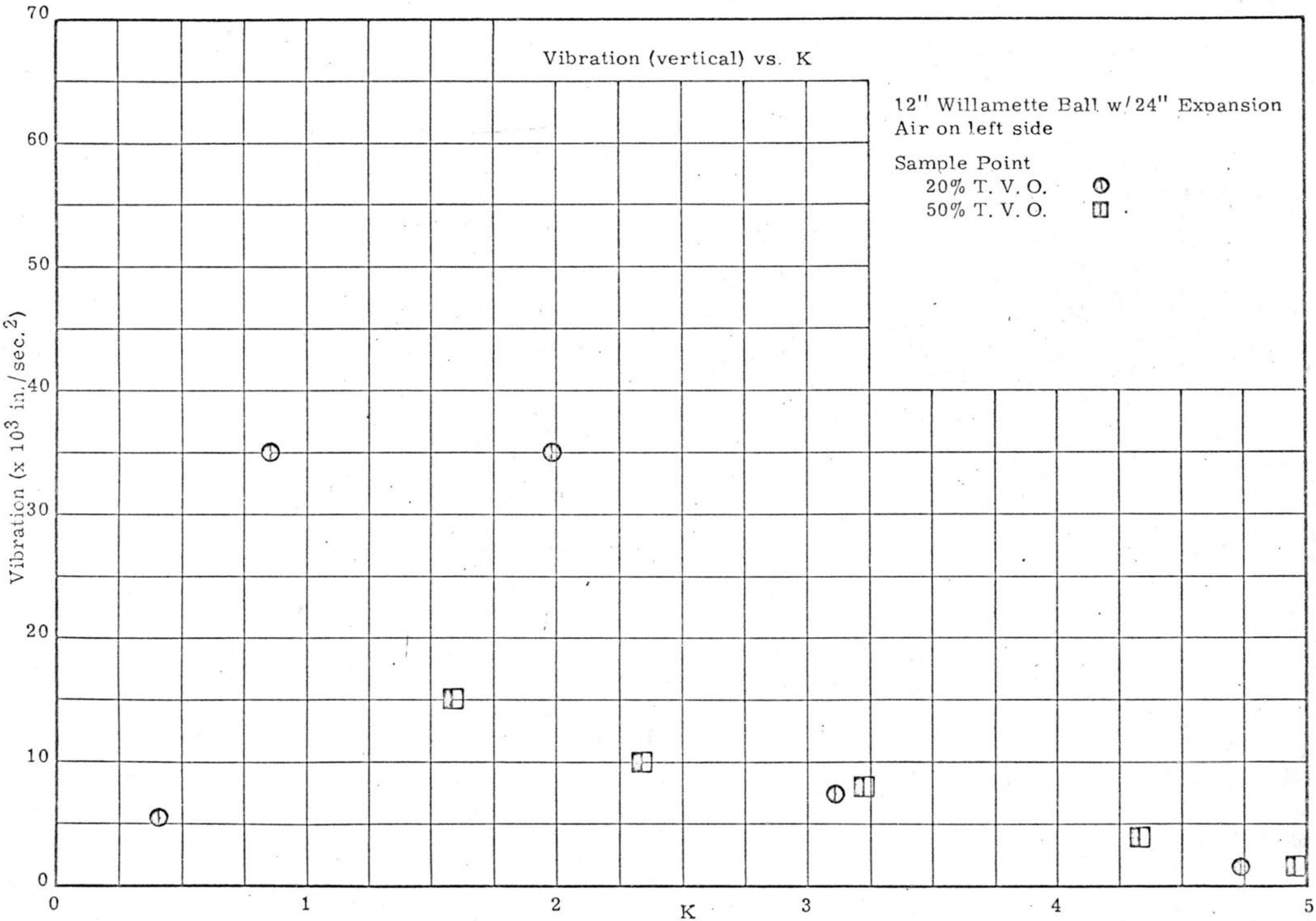

Hydrophone Output vs K
12" Butterfly w/24" Expansion
No air, No by-pass
BW 10 - 200 Kc
Sample Point
35% T.V.O.
Hydrophone Output
K
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10



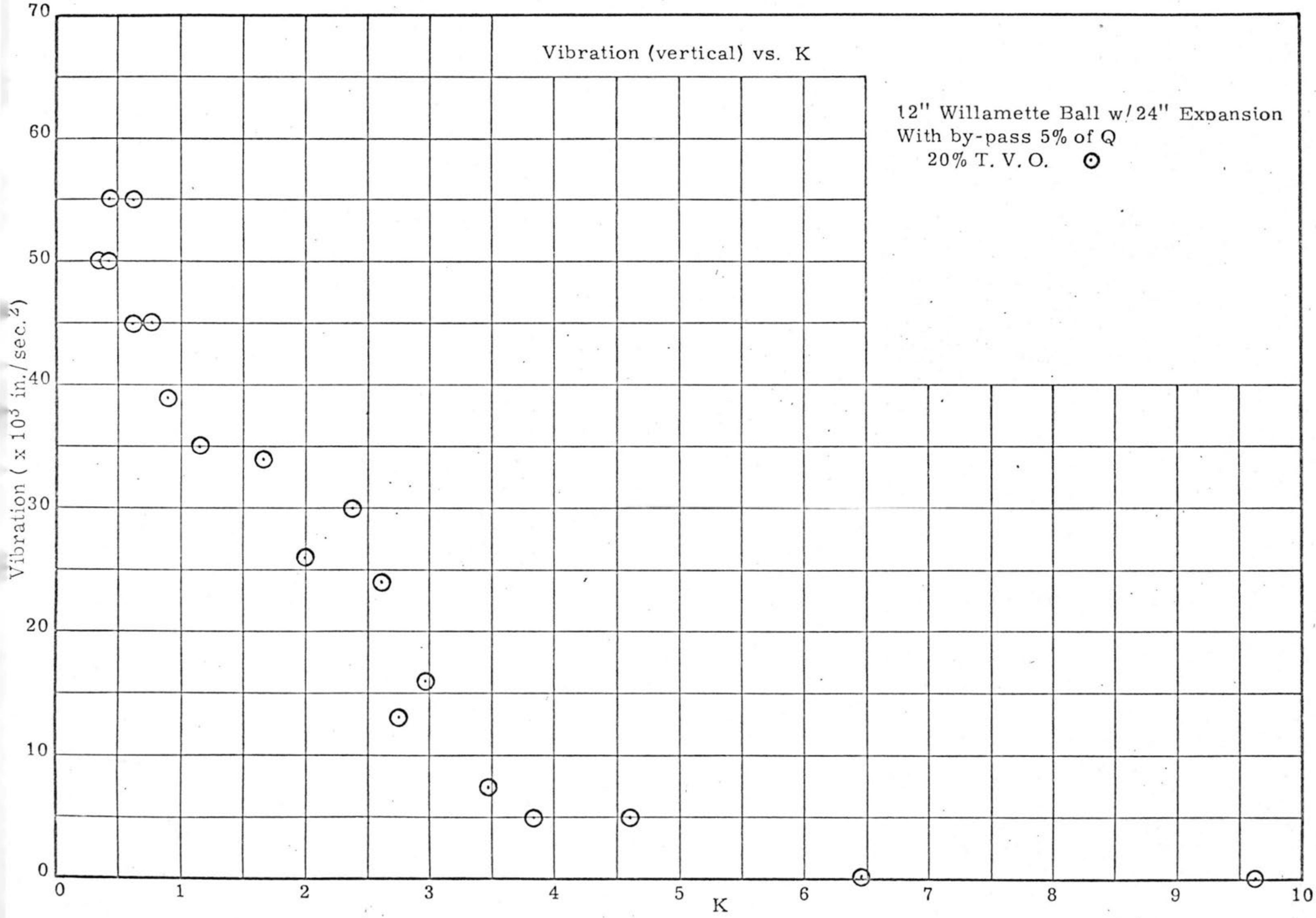
Hydrophone Output vs. K
12" Butterfly w/24" Expansion
No air, No by-pass
BW 10 - 200 Kc
Sample Point
50% T. V. O.
Hydrophone Output
K
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10


Hydrophone Output vs. K
12" Butterfly w/24" Expansion
No air, No by-pass
BW 10 - 200 Kc
Sample Point
70% T.V.O.
Hydrophone Output
K
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10

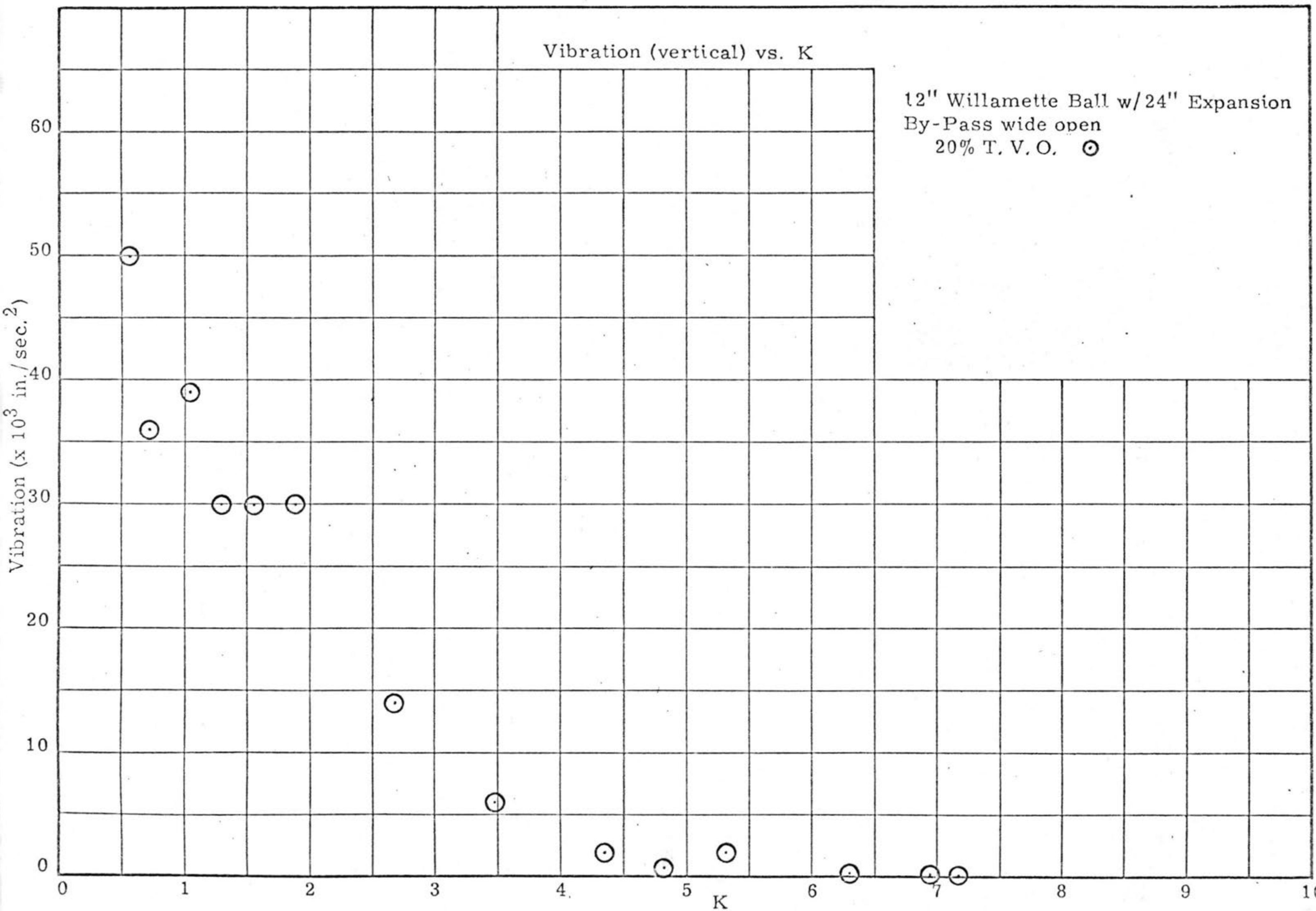

Vibration (vertical) vs. K
12" Willamette Ball w/24" Expansion
Air on right side
Sample Point
20% T. V. O.
50% T. V. O.
Vibration (x 10^3 in./sec.^2)
20
10
0
0
1
2
3
4
5
K



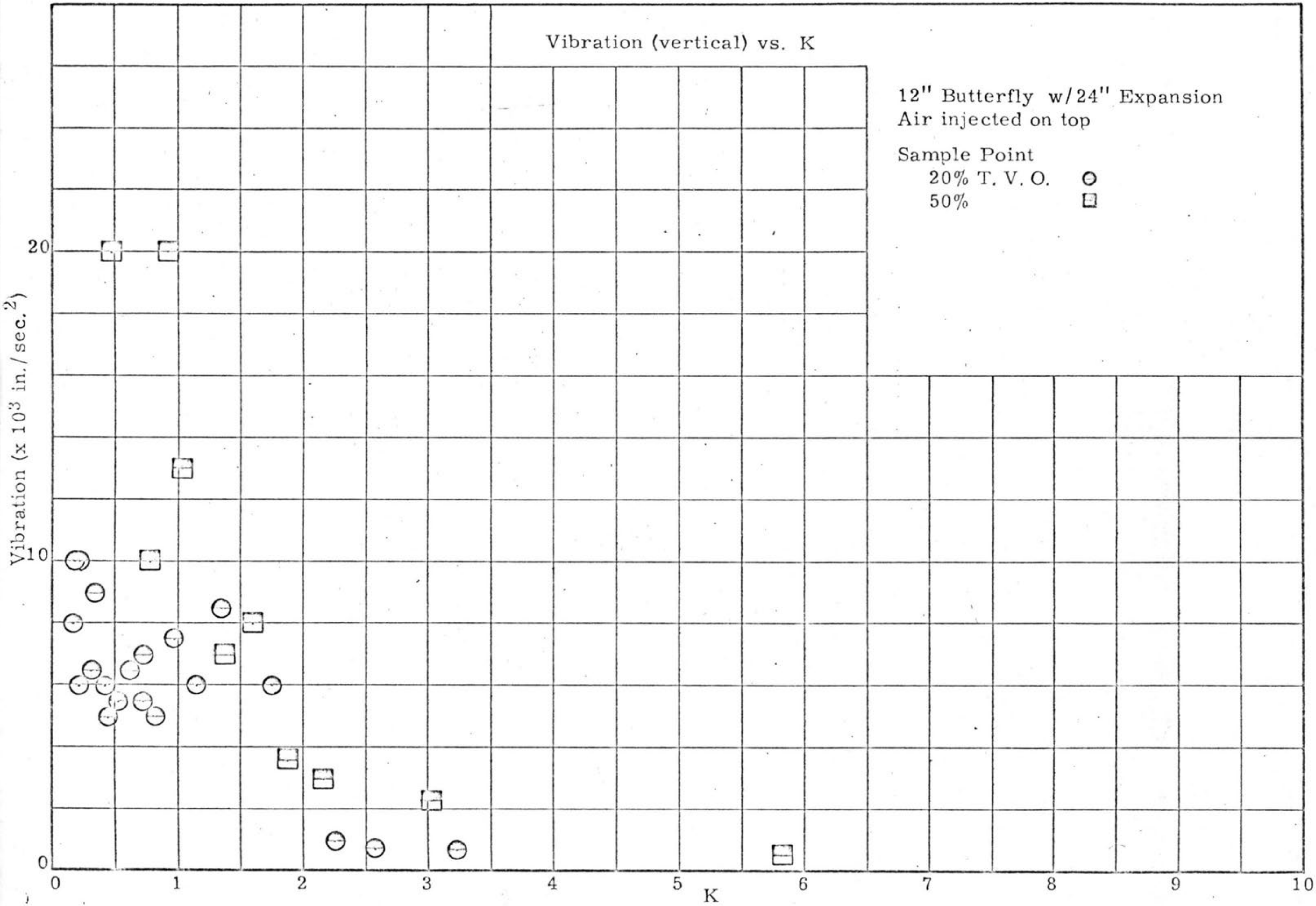
Vibration (vertical) vs. K
12" Willamette Ball w/24" Expansion
Air on left side
Sample Point
20% T. V. O.
50% T. V. O.
Vibration (x 10^3 in./sec.^{2})
K
0
10
20
30
40
50
60
70
1
2
3
4
5



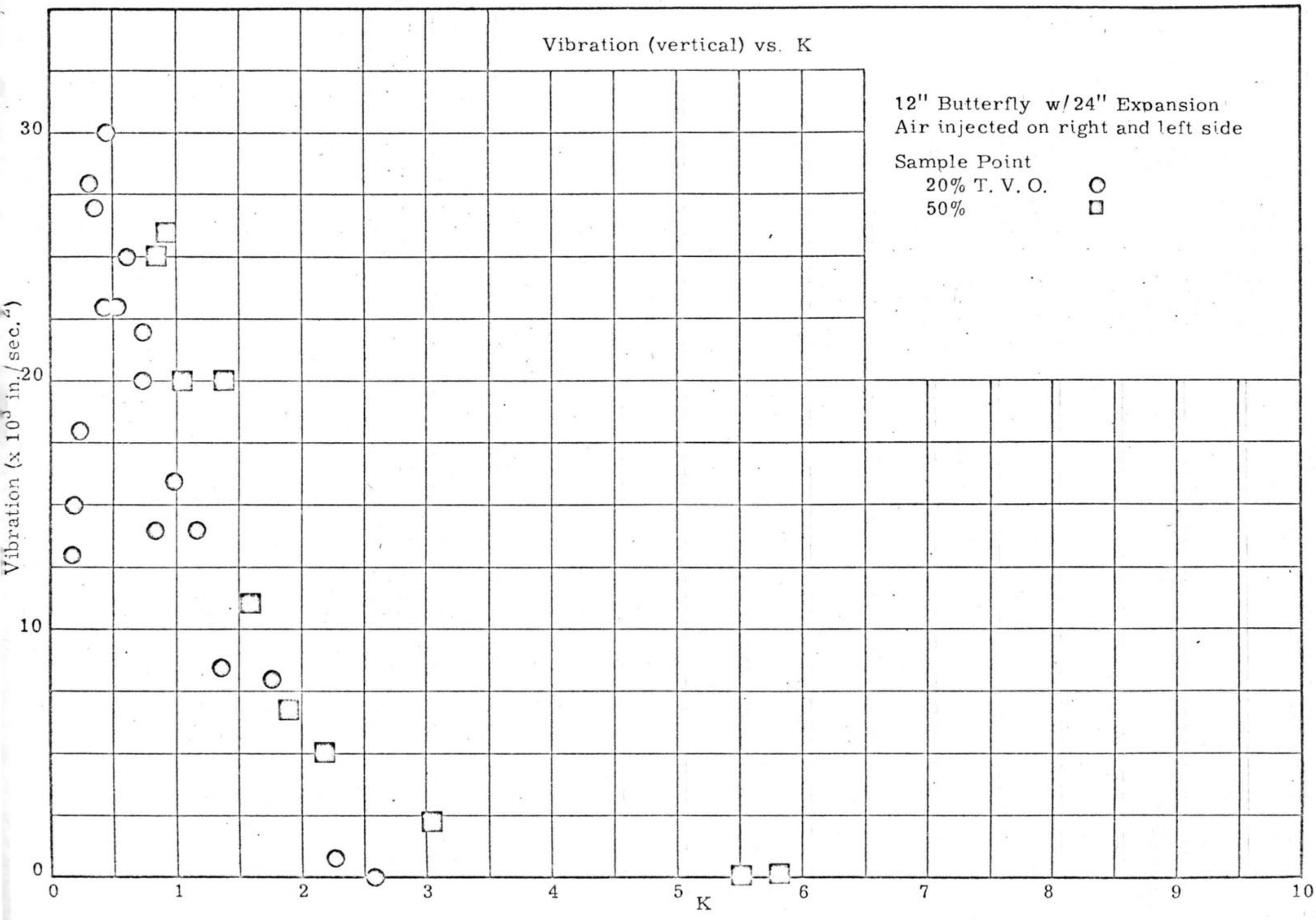
Vibration (vertical) vs. K
12" Willamette Ball w/24" Expansion
With by-pass 5% of Q
20% T. V. O.
Vibration (x 10³ in./sec.²)
K
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10

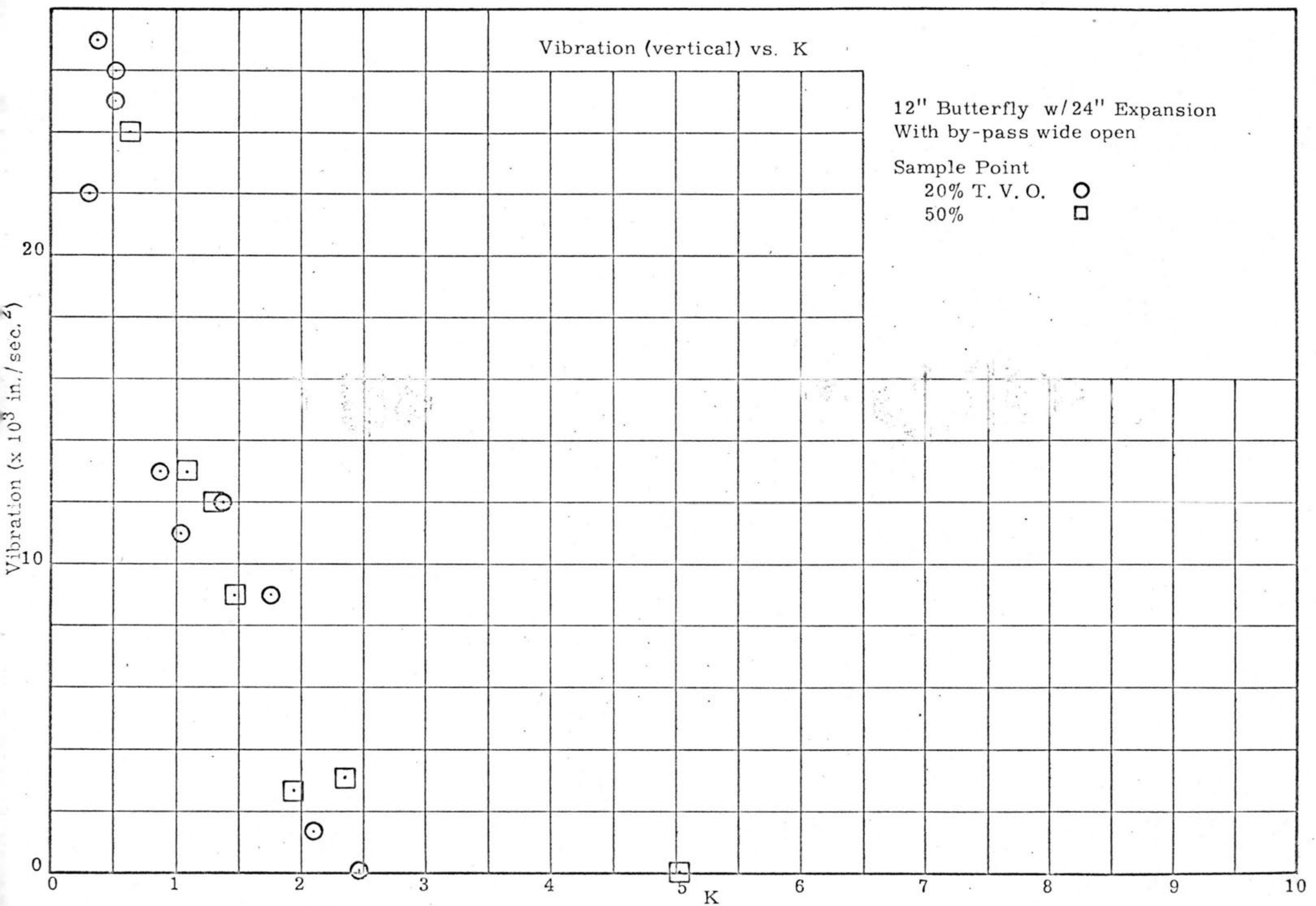


Vibration (vertical) vs. K
12" Willamette Ball w/24" Expansion
By-Pass wide open
20% T. V. O.
Vibration (x 10^3 in./sec.^2)
0
10
20
30
40
50
60
K
0
1
2
3
4
5
6
7
8
9
10

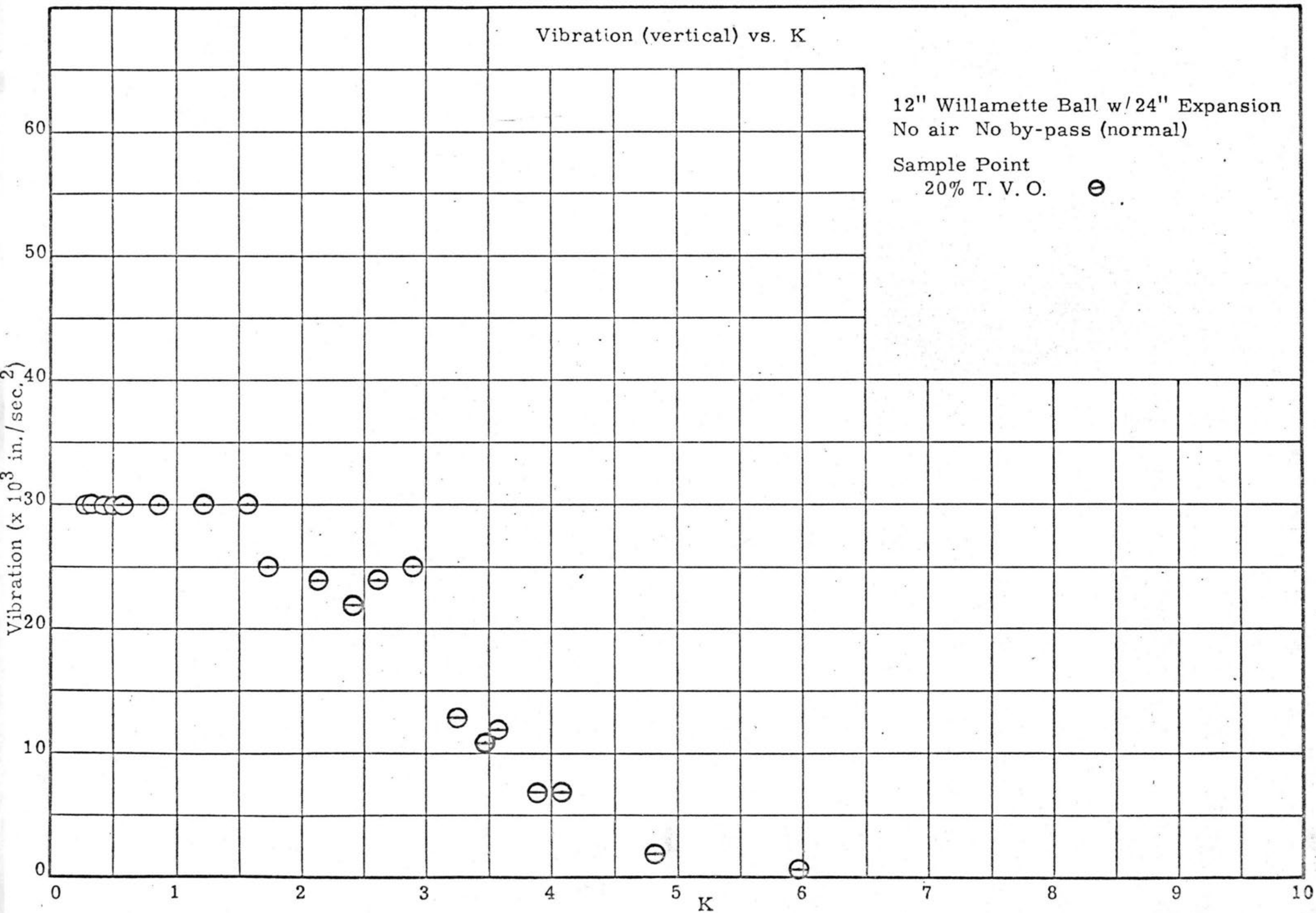


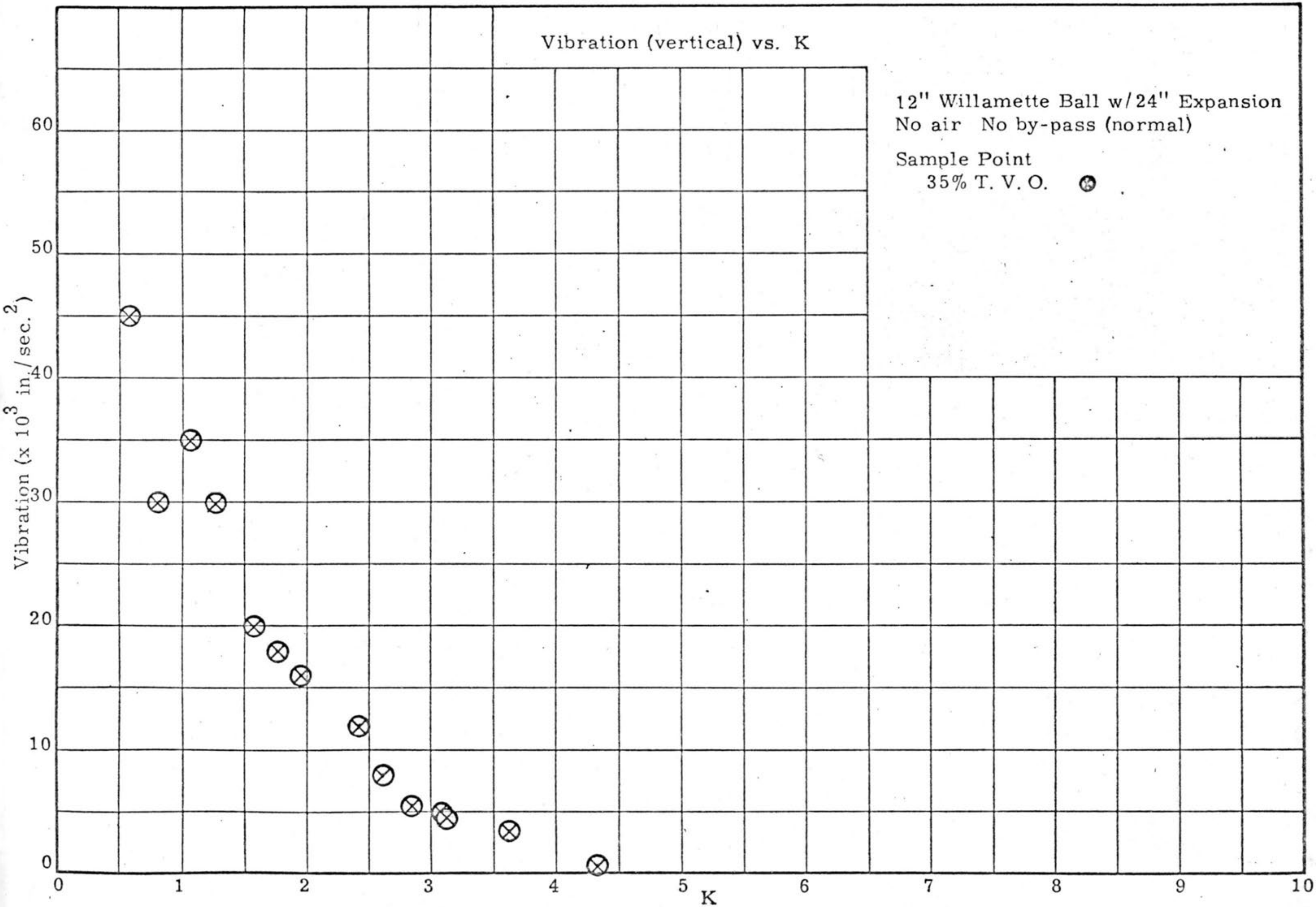
Vibration (vertical) vs. K
12" Butterfly w/24" Expansion
Air injected on top
Sample Point
20% T. V. O.
50%
Vibration (x 10^3 in./sec.^2)
K
0
10
20
0
1
2
3
4
5
6
7
8
9
10


Vibration (vertical) vs. K
12" Butterfly w/24" Expansion
Air injected on right and left side
Sample Point
20% T. V. O.
50%
Vibration (x 10³ in./sec.²)
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
K

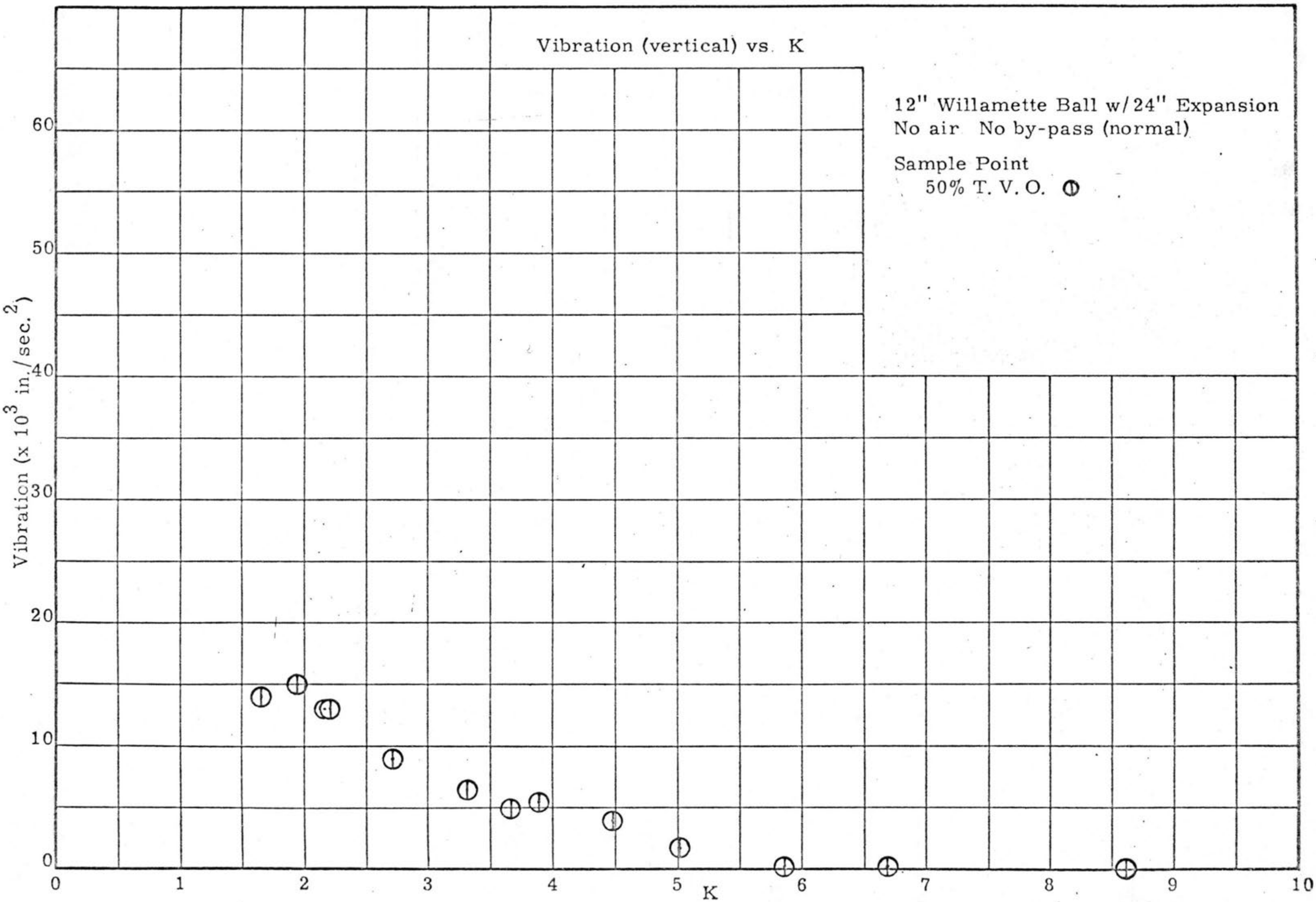


Vibration (vertical) vs. K
12" Butterfly w/24" Expansion
With by-pass wide open
Sample Point
20% T. V. O.
50%
Vibration (x 10^3 in./sec.^2)
20
10
0
0
1
2
3
4
5
6
7
8
9
10
K

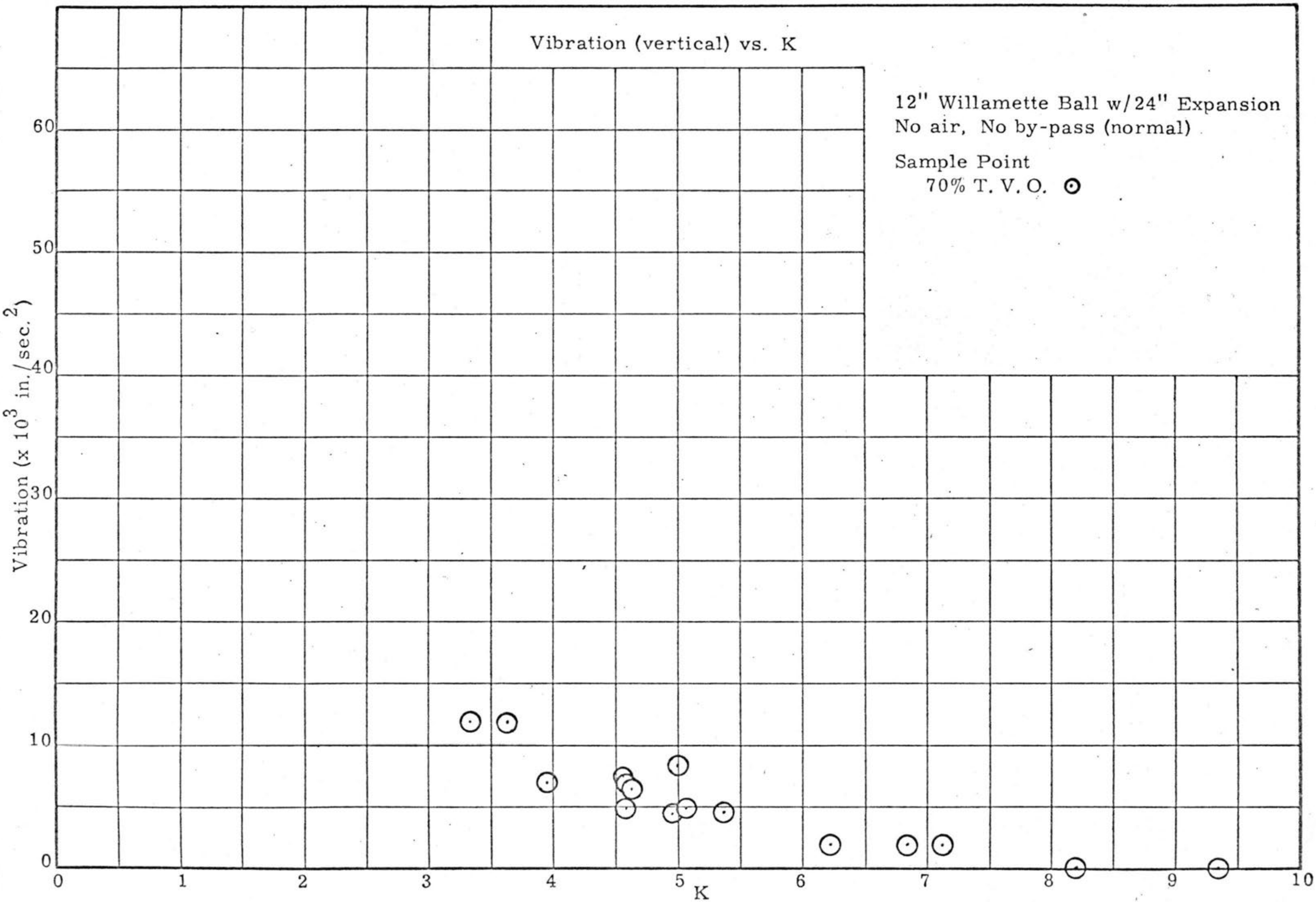

Vibration (vertical) vs. K
12" Willamette Ball w/24" Expansion
No air No by-pass (normal)
Sample Point
20% T. V. O.
Vibration (x 10^3 in./sec.^{2})
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
K



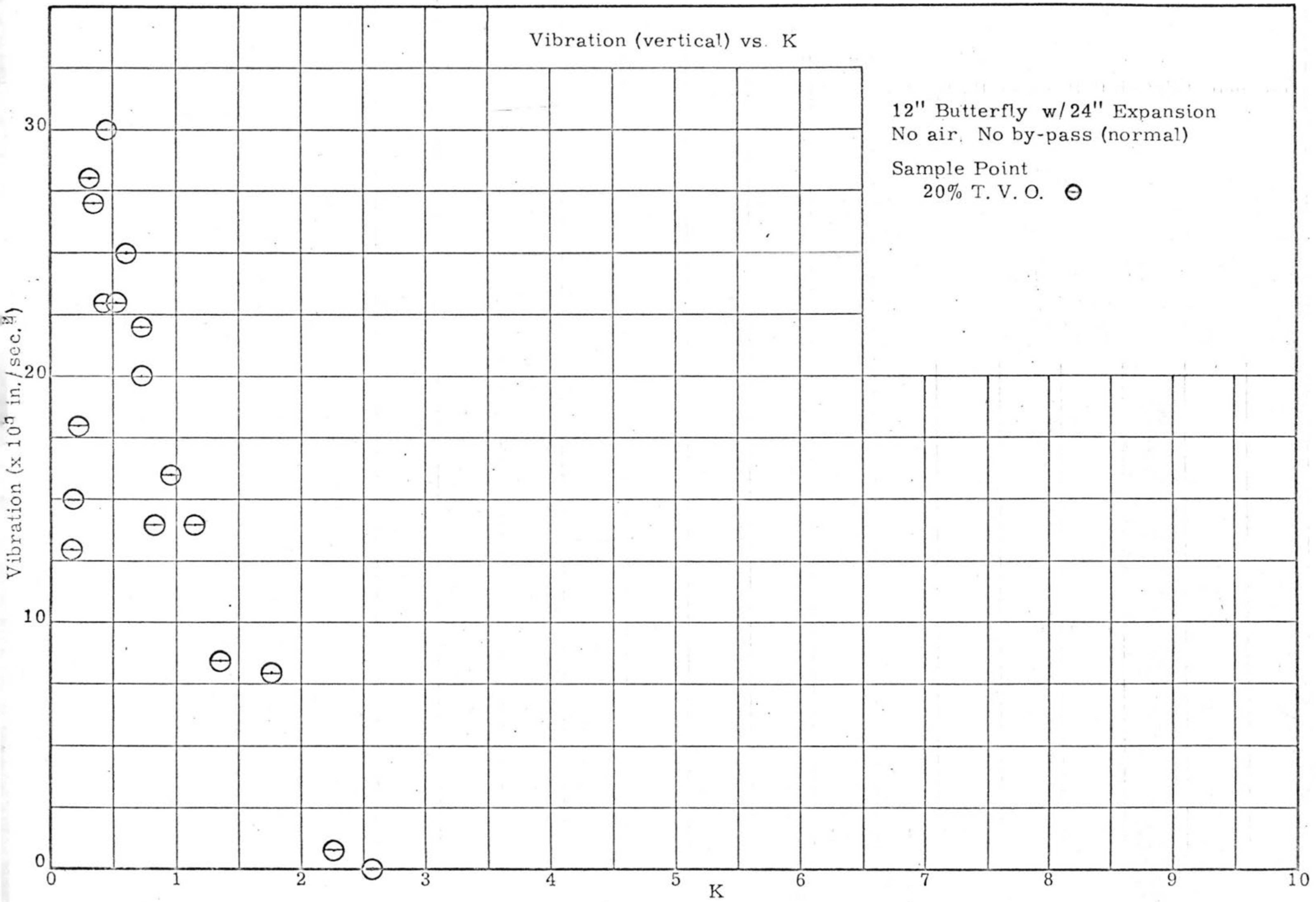
Vibration (vertical) vs. K
12" Willamette Ball w/24" Expansion
No air No by-pass (normal)
Sample Point
35% T. V. O.
Vibration (x 10^3 in./sec.^2)
0
10
20
30
40
50
60
0
1
2
3
4
5
6
7
8
9
10
K

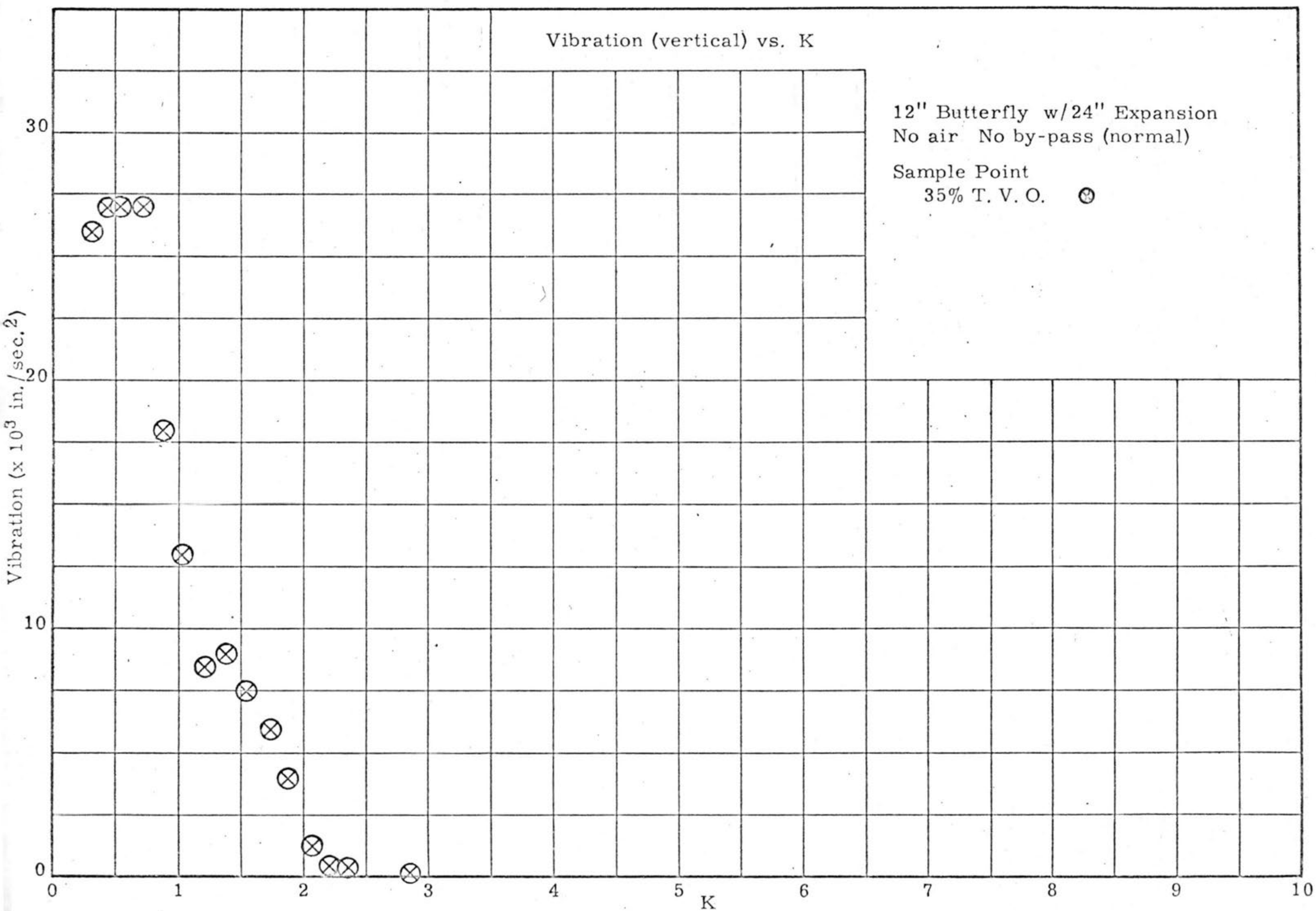


Vibration (vertical) vs. K
12" Willamette Ball w/24" Expansion
No air No by-pass (normal)
Sample Point
50% T. V. O.
Vibration (x 10^3 in./sec.^{2})
K
0
10
20
30
40
50
60
0
1
2
3
4
5
6
7
8
9
10

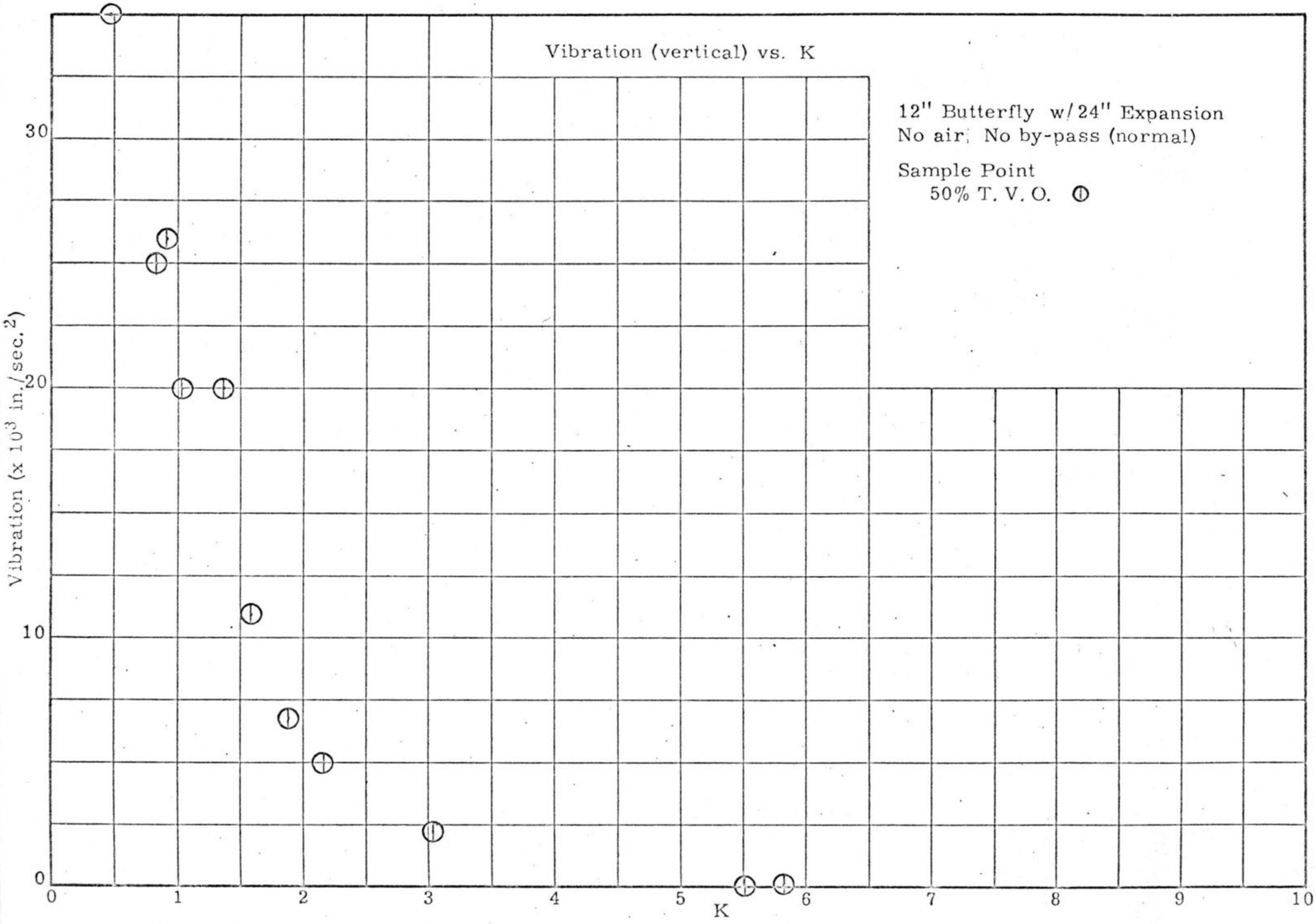


Vibration (vertical) vs. K
12" Willamette Ball w/24" Expansion
No air, No by-pass (normal)
Sample Point
70% T. V. O.
Vibration (x 10^3 in./sec.^2)
K
0
10
20
30
40
50
60
1
2
3
4
5
6
7
8
9
10

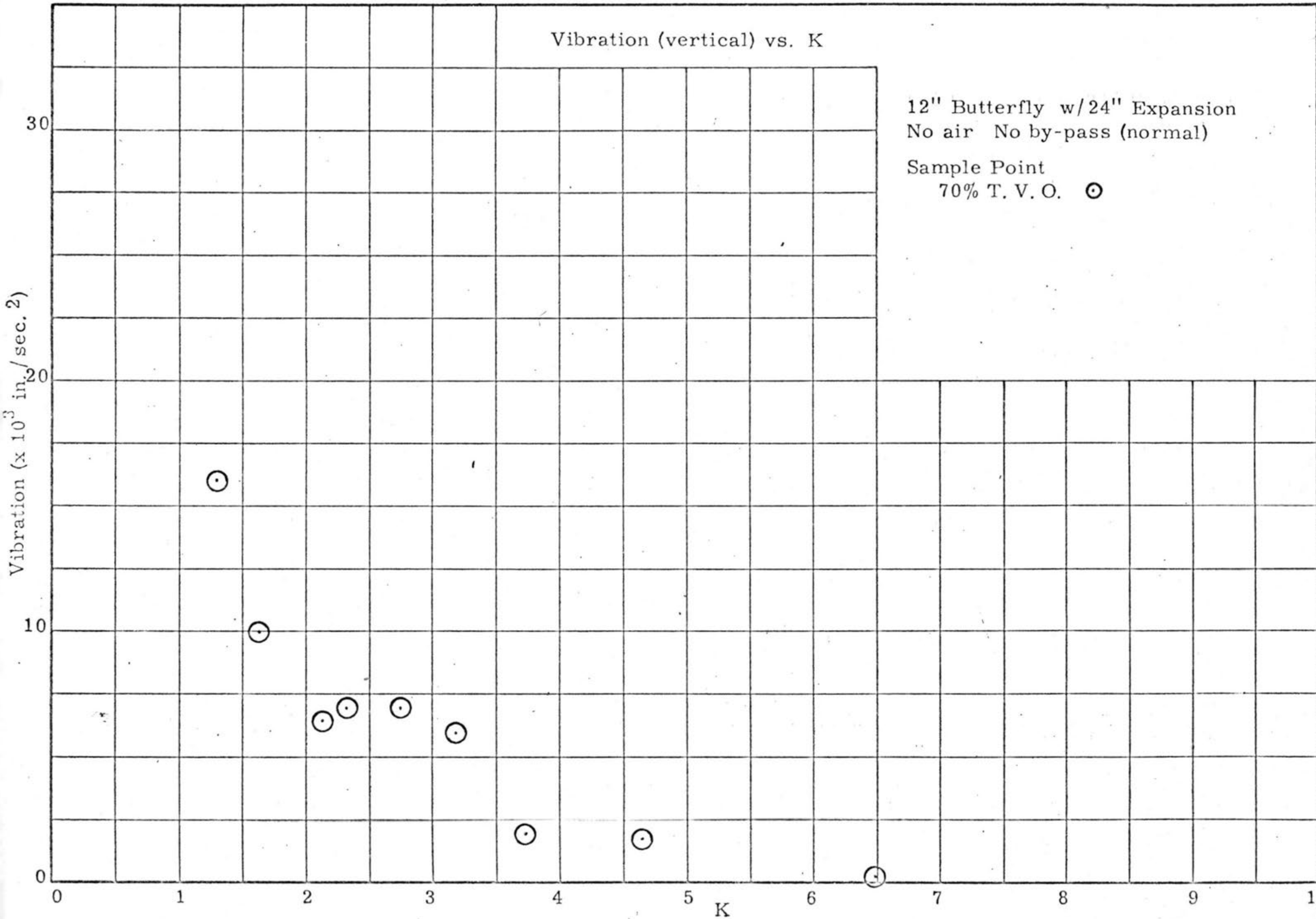

Vibration (vertical) vs. K
12" Butterfly w/24" Expansion
No air, No by-pass (normal)
Sample Point
20% T. V. O.
Vibration (x 10^-3 in./sec.^2)
K
0
10
20
30
0
1
2
3
4
5
6
7
8
9
10



Vibration (vertical) vs. K
12" Butterfly w/24" Expansion
No air No by-pass (normal)
Sample Point
35% T. V. O.
Vibration (x 10^3 in./sec.^2)
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
K

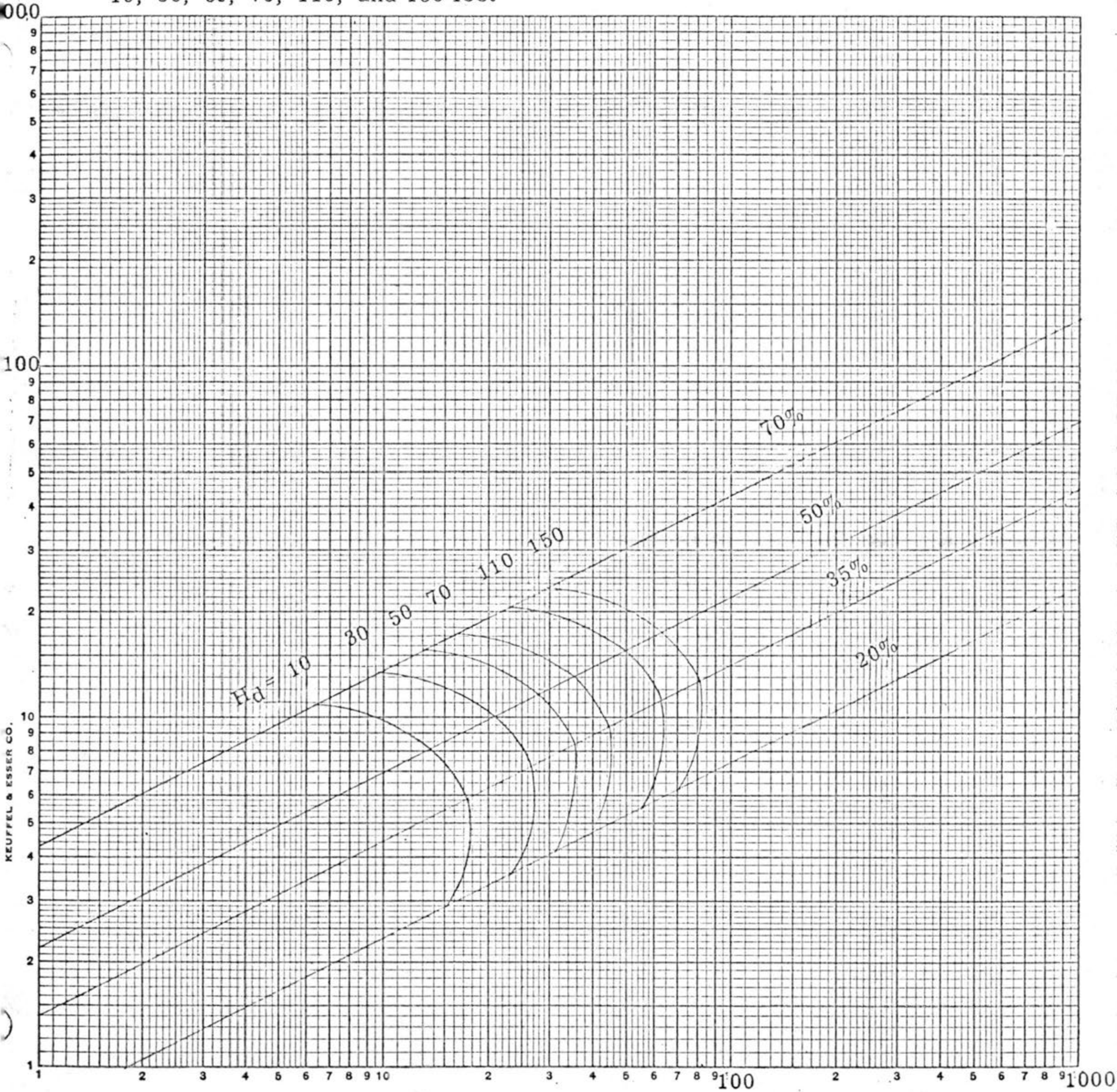


Vibration (vertical) vs. K
12" Butterfly w/24" Expansion
No air; No by-pass (normal)
Sample Point
50% T. V. O.
Vibration (x 10^3 in./sec.^2)
K
0
10
20
30
0
1
2
3
4
5
6
7
8
9
10



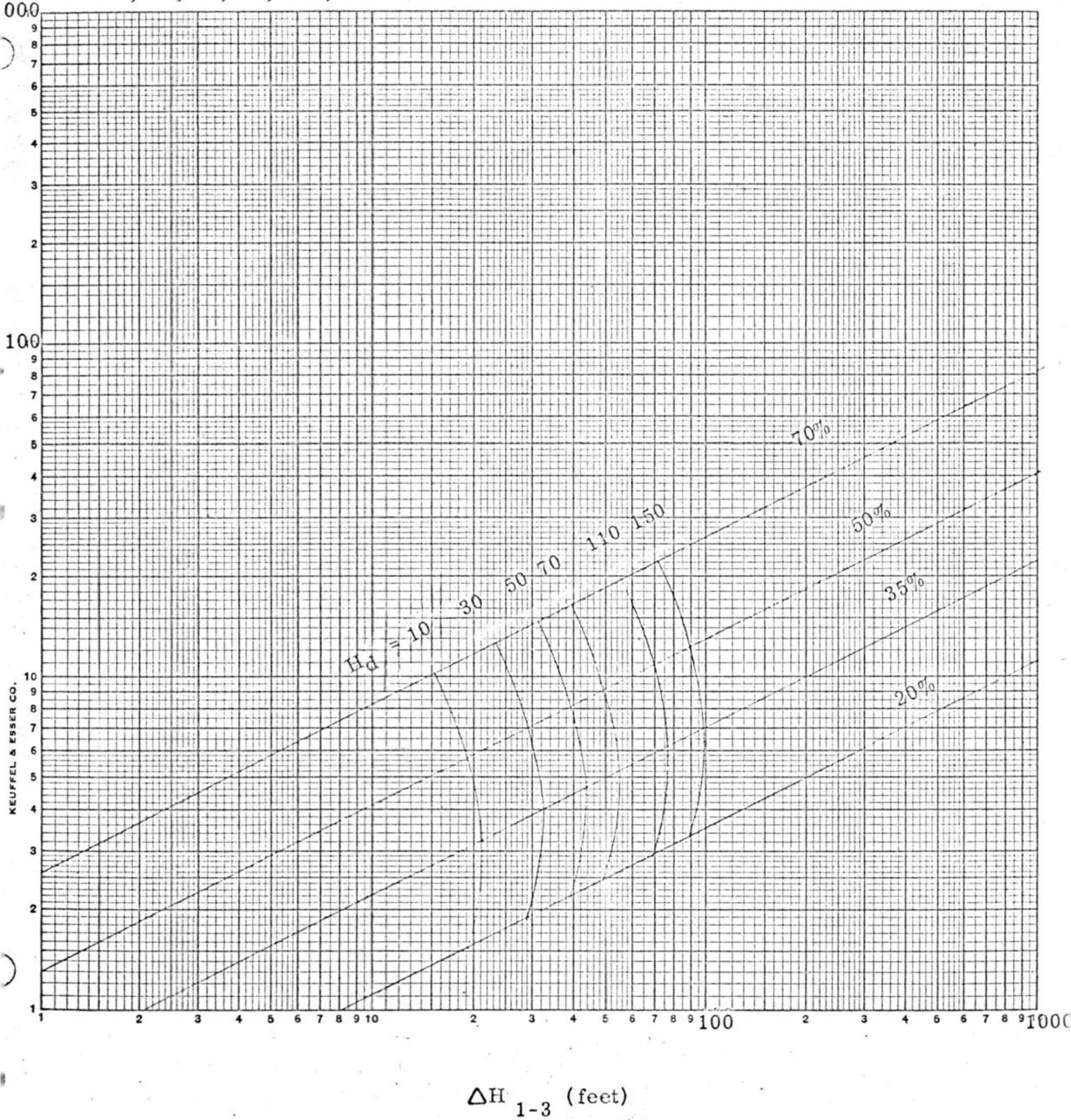
Vibration (vertical) vs. K
12" Butterfly w/24" Expansion
No air No by-pass (normal)
Sample Point
70% T. V. O.
Vibration (x 10^3 in./sec. 2)
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
K

ΔH vs. Q vs. H_d vs. cavitating or non-cavitating conditions.
12" Willamette Valve
Incipient critical Sigma lines for downstream pressure heads of
10, 30, 50, 70, 110, and 150 feet



ΔH (feet)

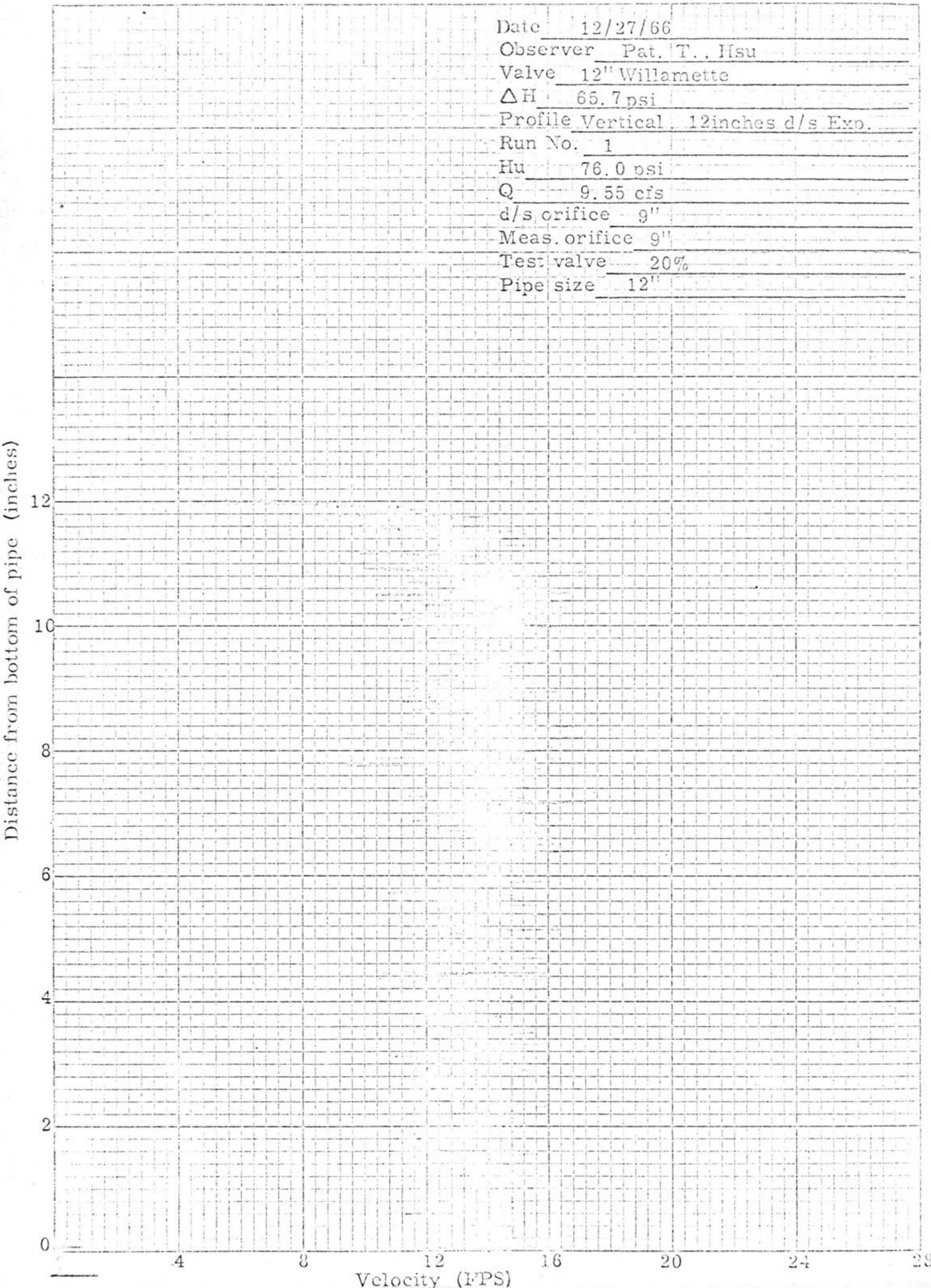
ΔH vs. Q vs. H_d vs. cavitating or non-cavitating conditions.
12" Butterfly Valve
Incipient critical Sigma lines for downstream pressure heads of
10, 30, 50, 70, 110, and 150 feet



Appendix C Velocity Traverses

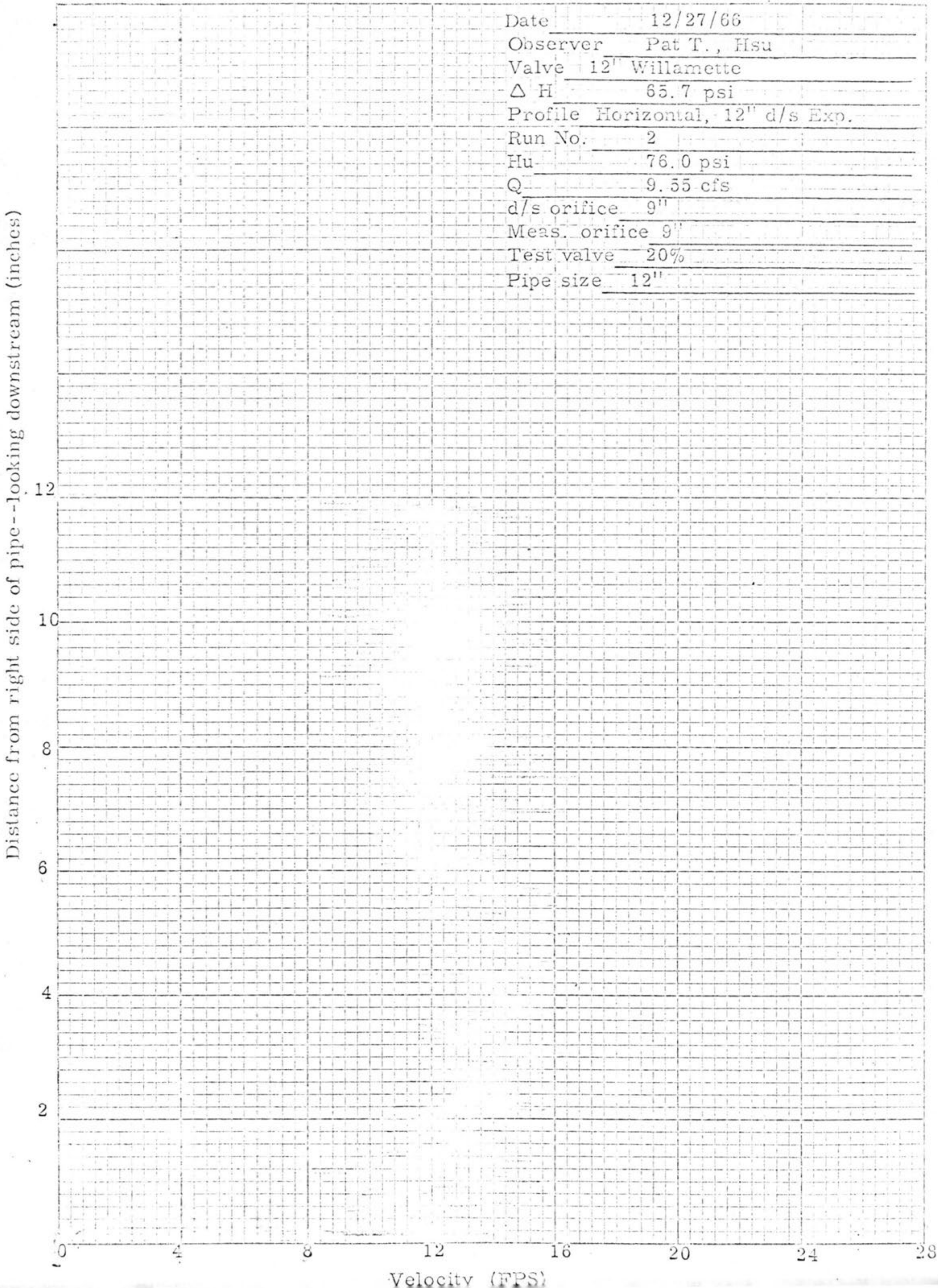
Velocity Traverse

Date 12/27/66
Observer Pat. T., Hsu
Valve 12" Willamette
ΔH 65.7 psi
Profile Vertical, 12inches d/s Exp.
Run No. 1
Hu 76.0 psi
Q 9.55 cfs
d/s orifice 9"
Meas. orifice 9"
Test valve 20%
Pipe size 12"

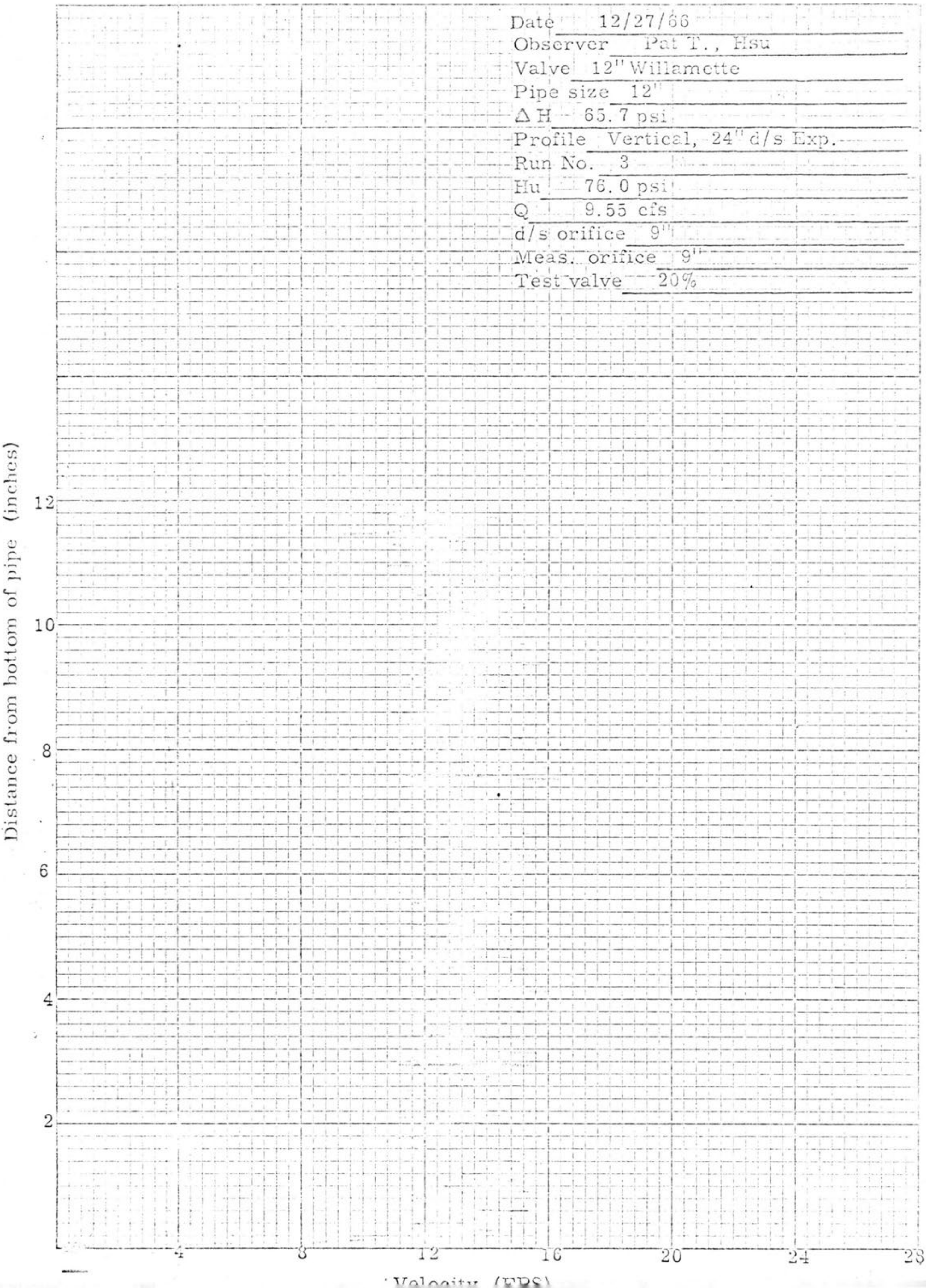


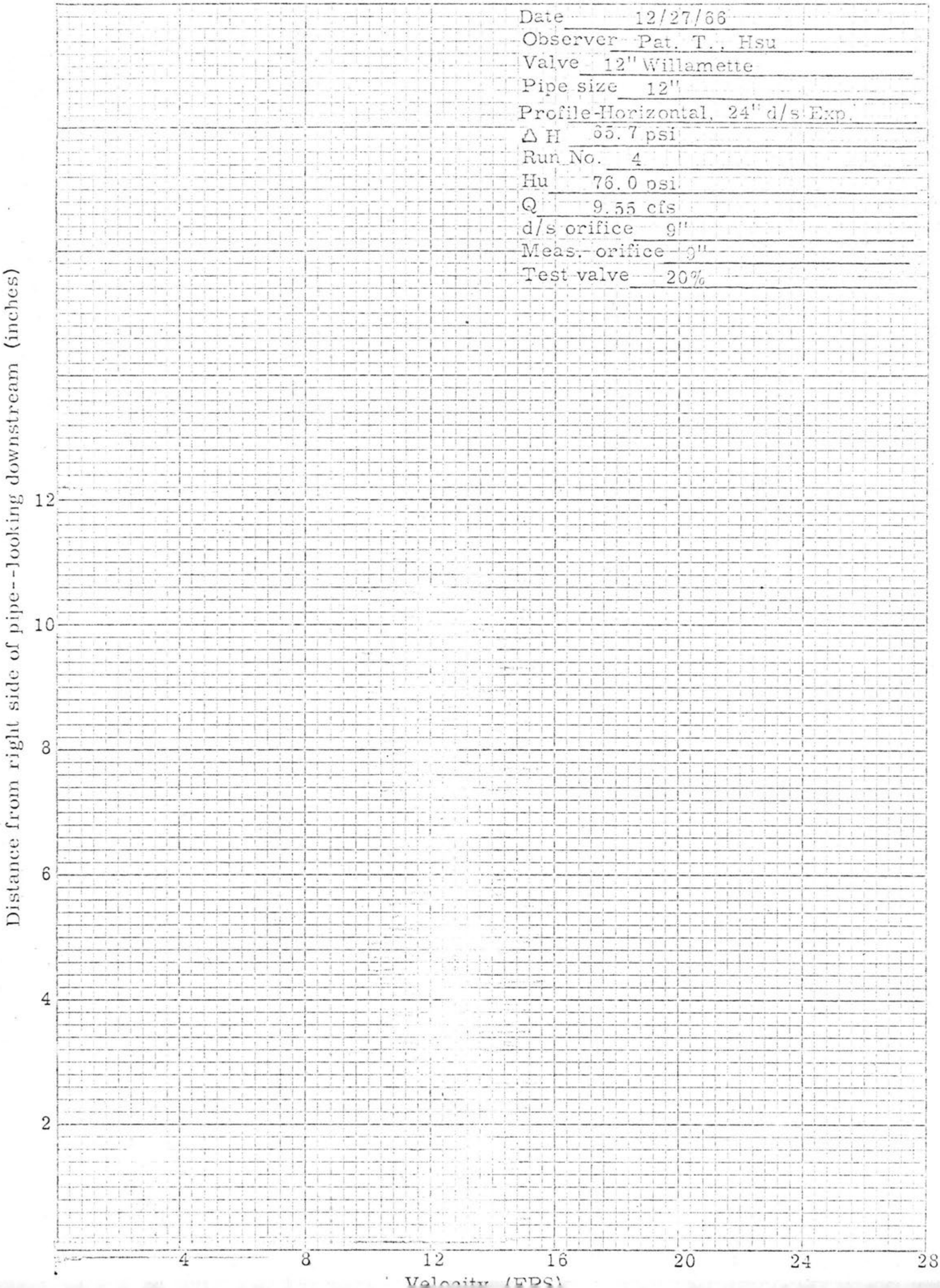
Velocity Traverse

Date 12/27/66
Observer Pat T., Hsu
Valve 12" Willamette
Δ H 65.7 psi
Profile Horizontal, 12" d/s Exp.
Run No. 2
Hu 76.0 psi
Q 9.55 cfs
d/s orifice 9"
Meas. orifice 9"
Test valve 20%
Pipe size 12"

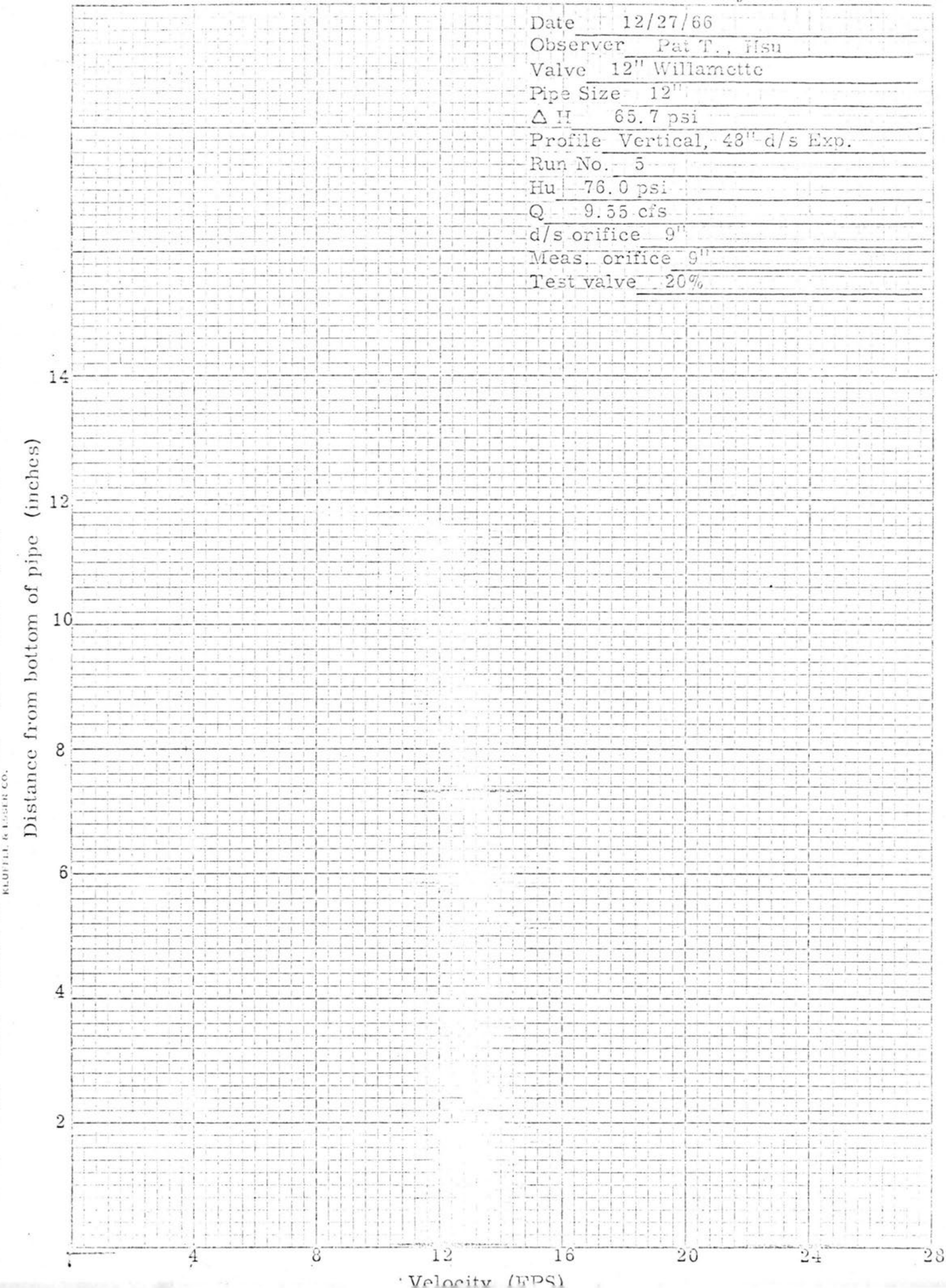


Date 12/27/66
Observer Pat T., Hsu
Valve 12" Willamette
Pipe size 12"
ΔH 65.7 psi
Profile Vertical, 24" d/s Exp.
Run No. 3
Hu 76.0 psi
Q 9.55 cfs
d/s orifice 9"
Meas. orifice 9"
Test valve 20%

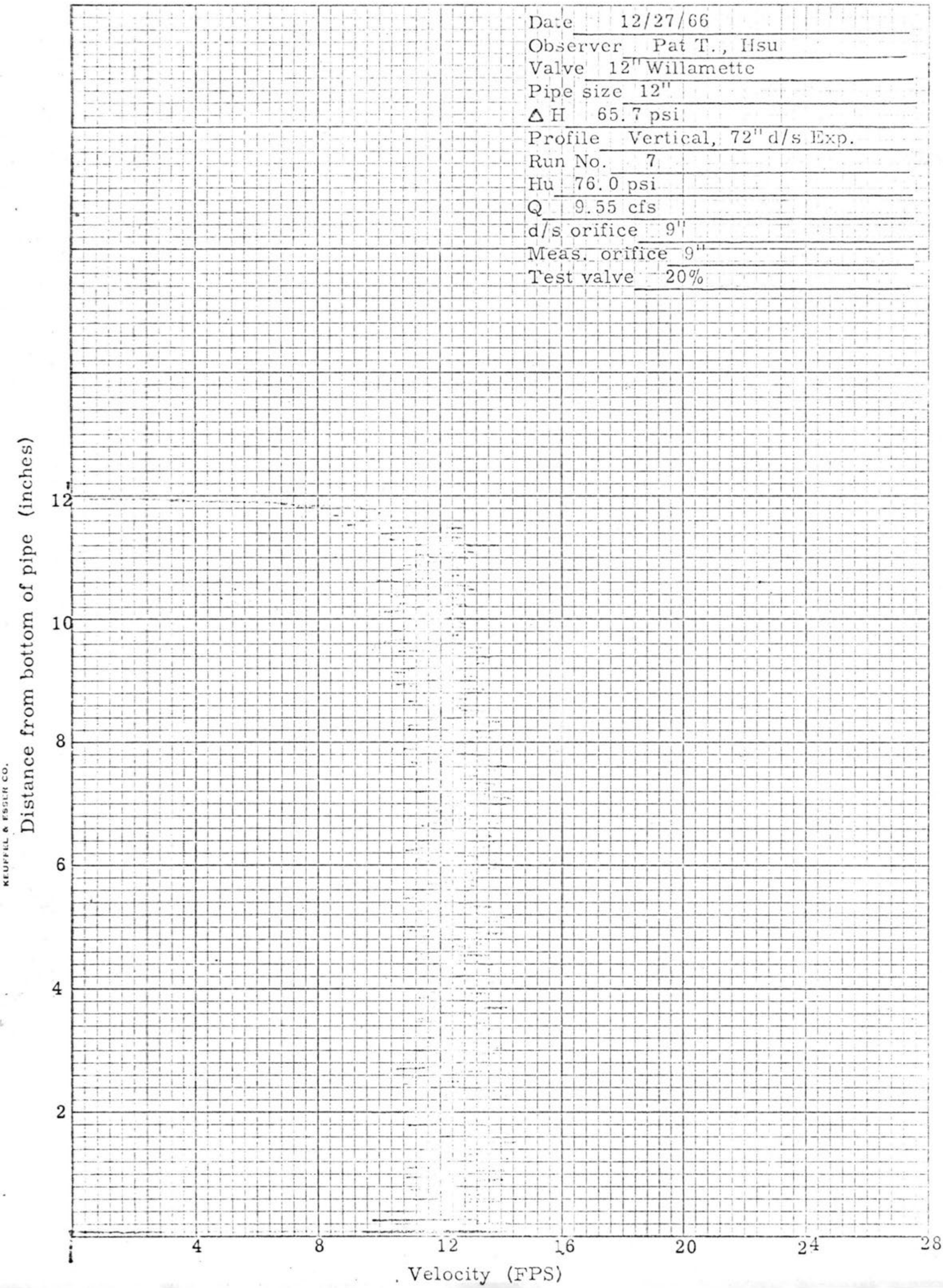



Date 12/27/66
Observer Pat. T., Hsu
Valve 12" Willamette
Pipe size 12"
Profile-Horizontal, 24" d/s Exp.
Δ H 65.7 psi
Run No. 4
Hu 76.0 psi
Q 9.55 cfs
d/s orifice 9"
Meas. orifice 9"
Test valve 20%
Distance from right side of pipe--looking downstream (inches)
12
10
8
6
4
2
4
8
12
16
20
24
28
Velocity (FPS)
KEUFFEL & ESSER CO.

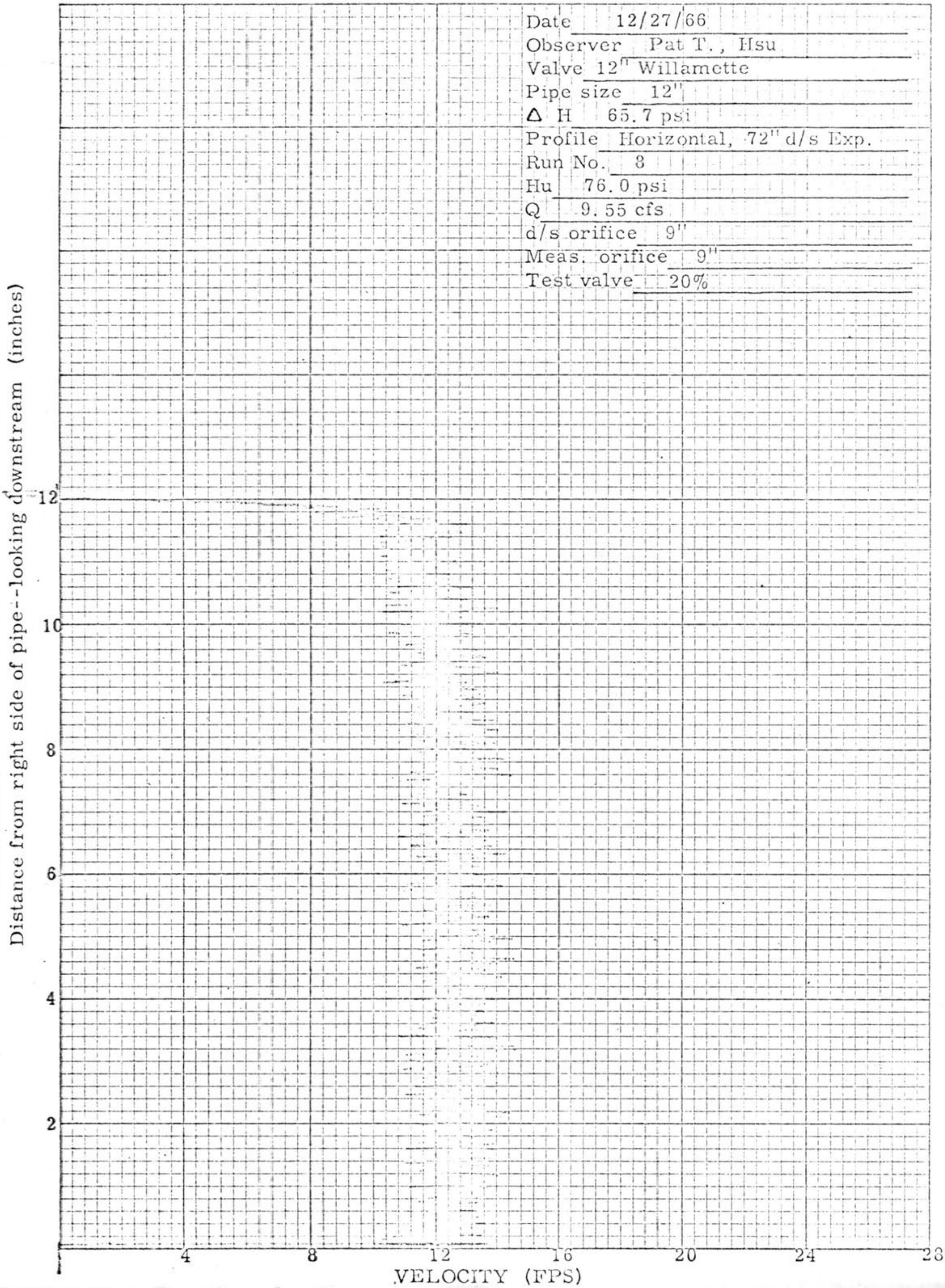
Velocity Traverse



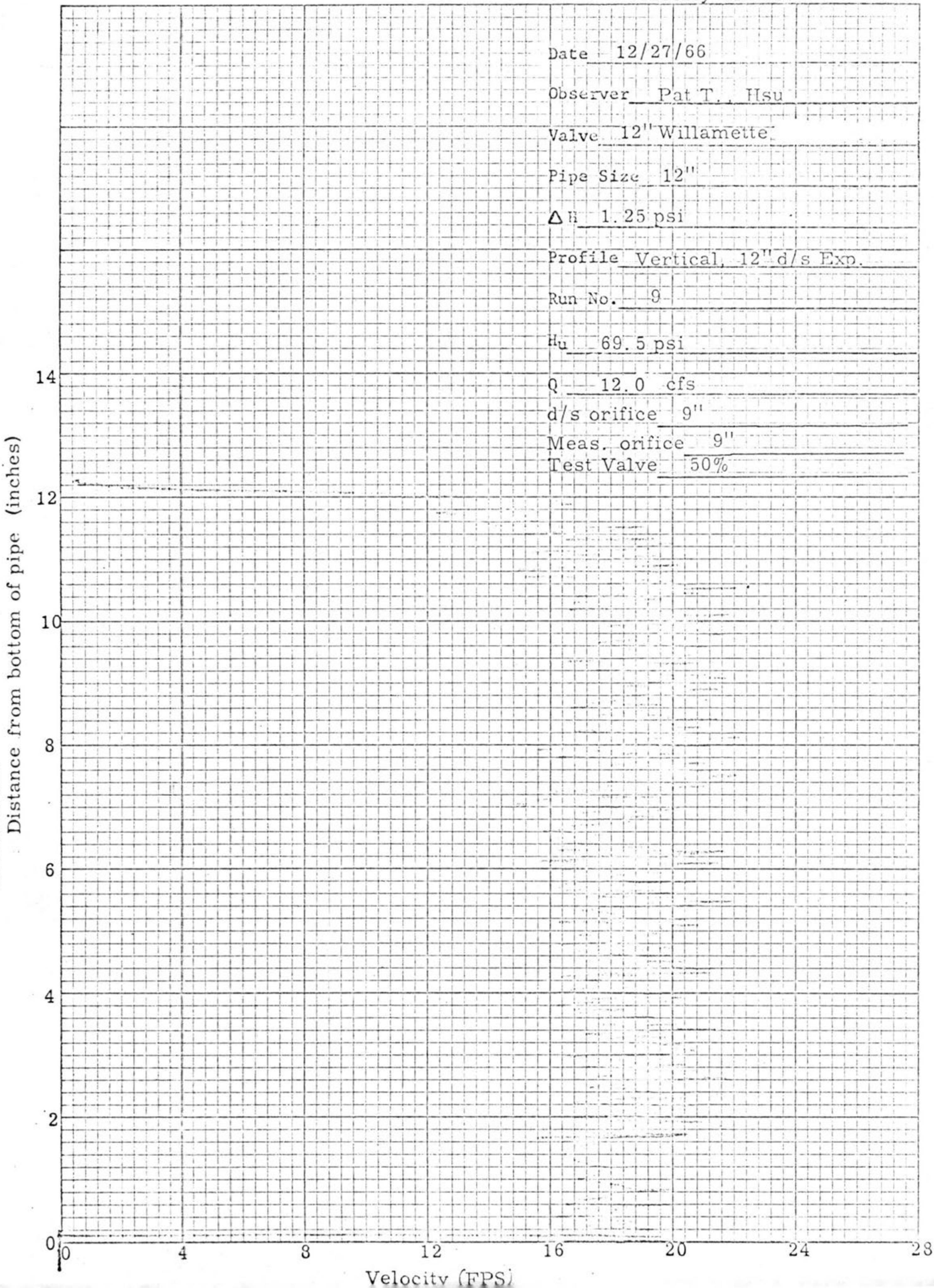
Velocity Traverse



Velocity Traverse



Velocity Traverse



Velocity Traverse

Date 12/27/66

Observer Pat T., Hsu

Valve 12" Willamette

Pipe Size 12"

ΔH 1.25 psi

Profile Horizontal, 12" d/s Exp.

Run No. 10

Hu 69.5

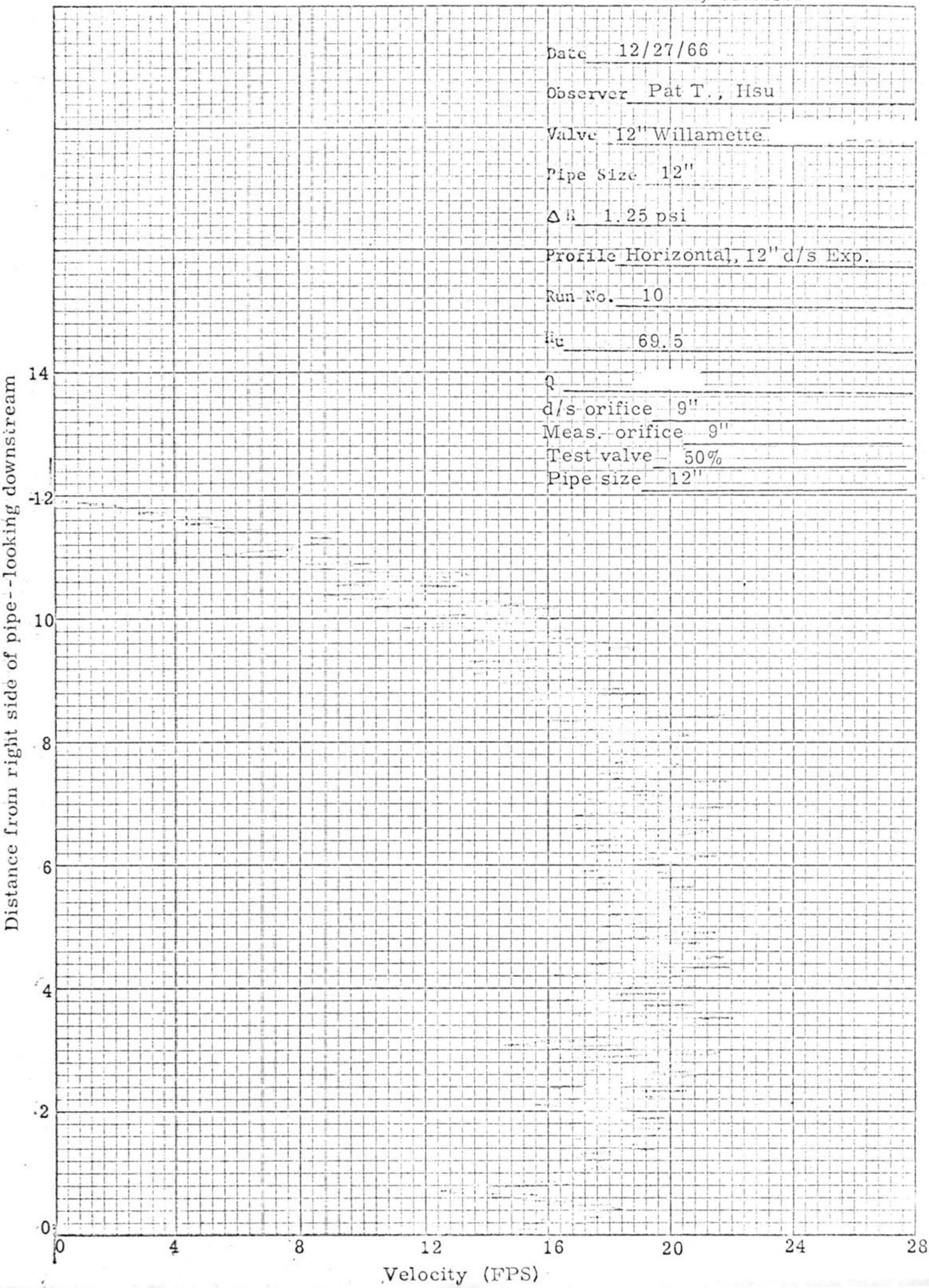
Q

d/s orifice 9"

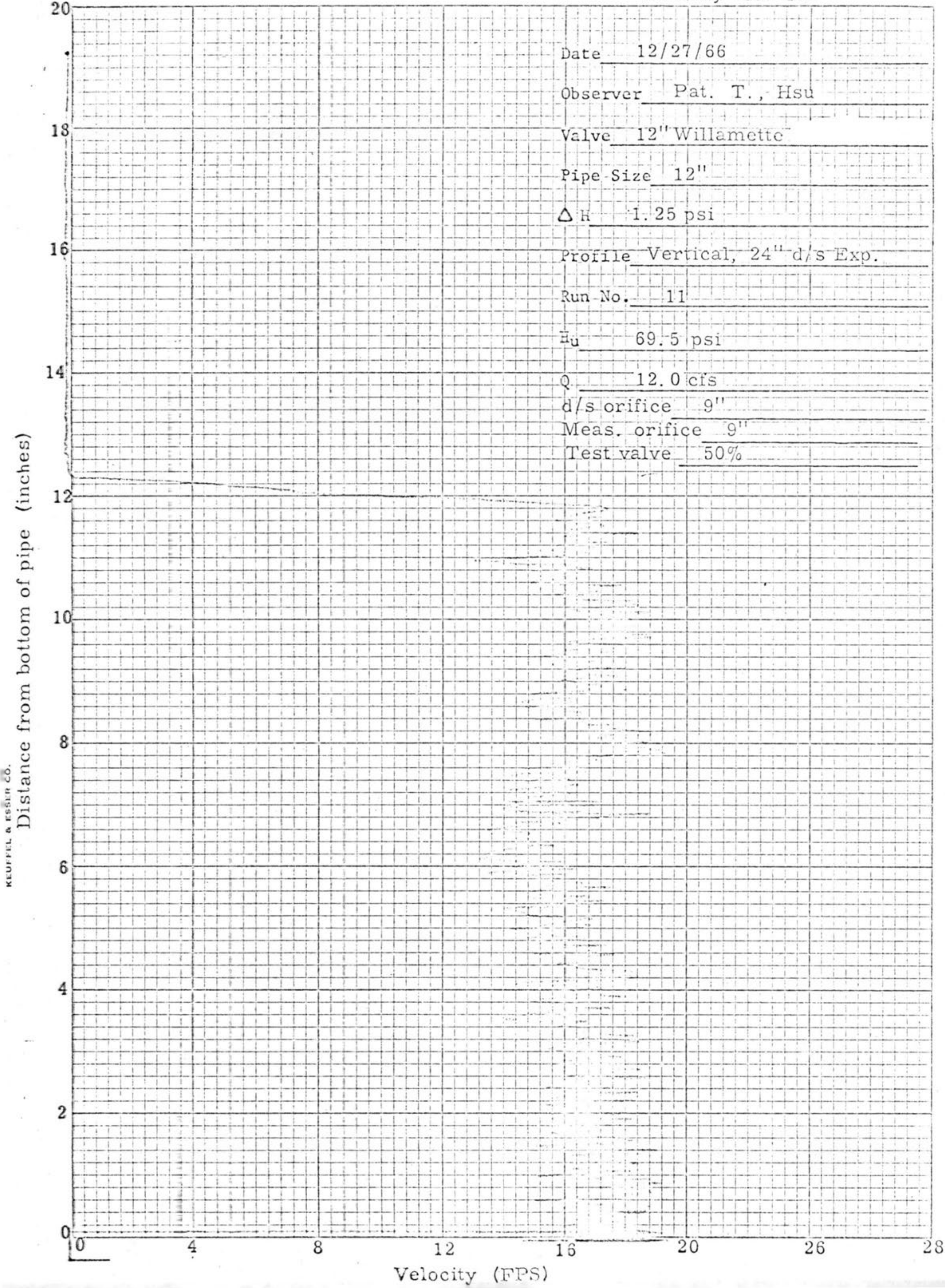
Meas. orifice 9"

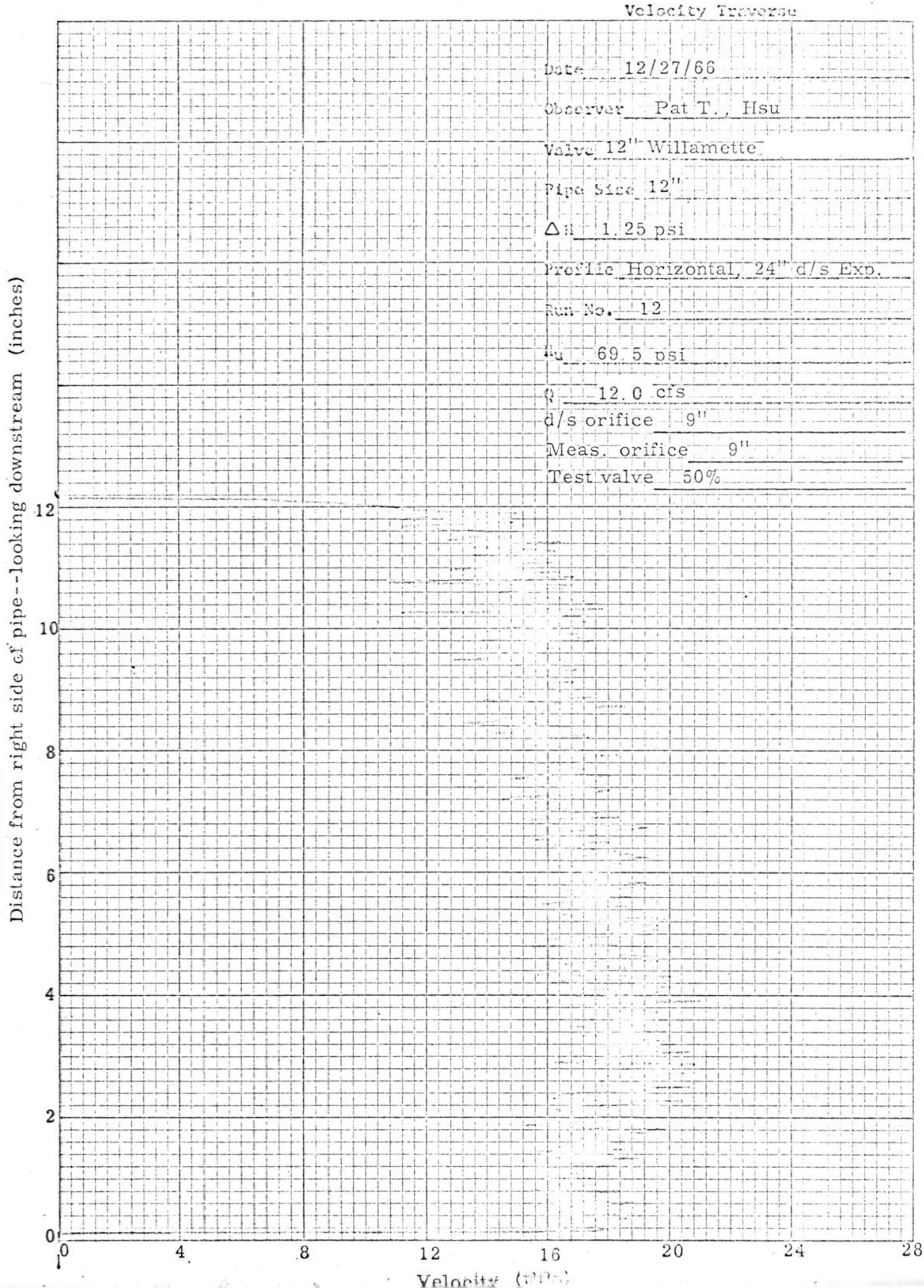
Test valve 50%

Pipe size 12"

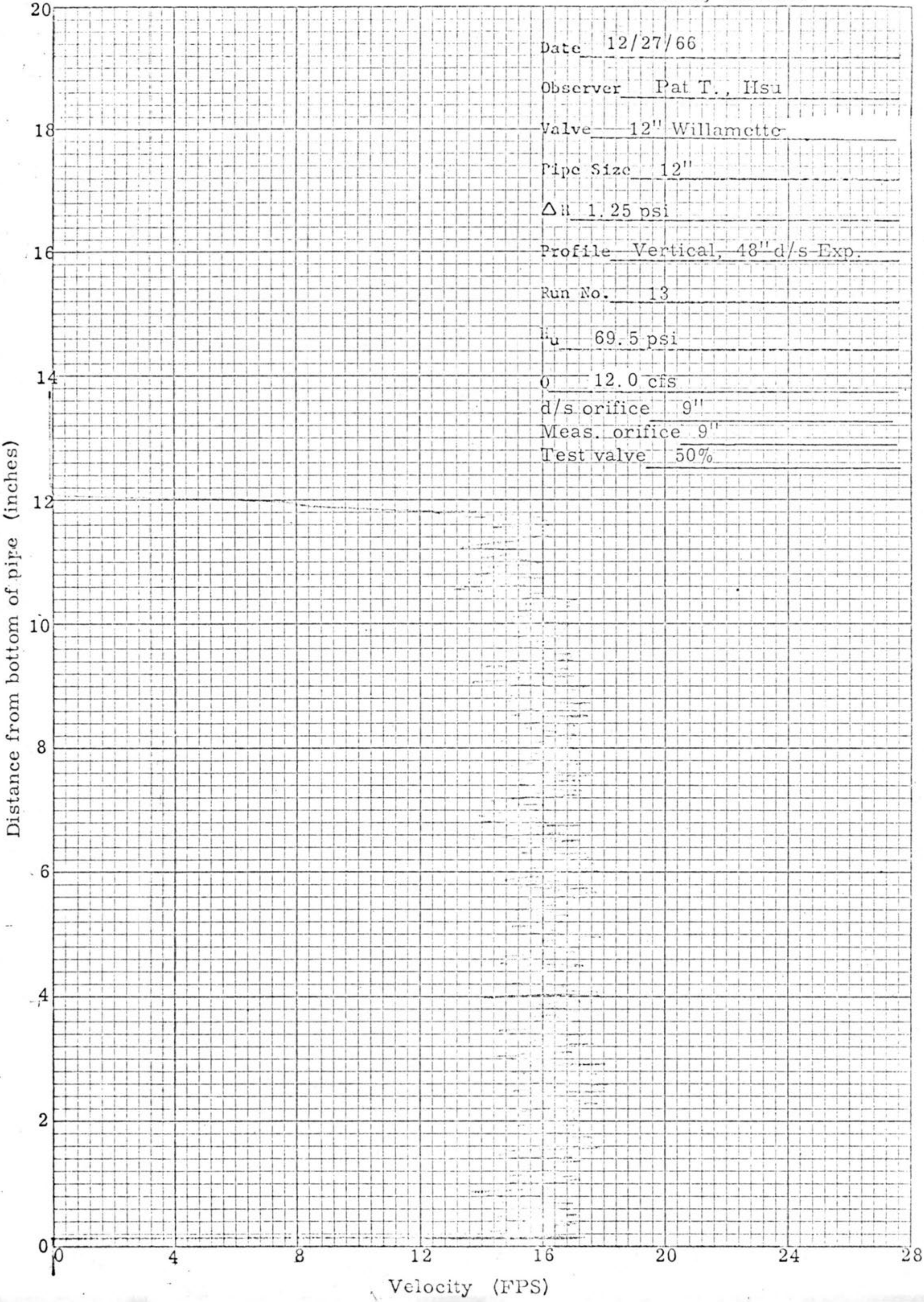


Velocity Traverse

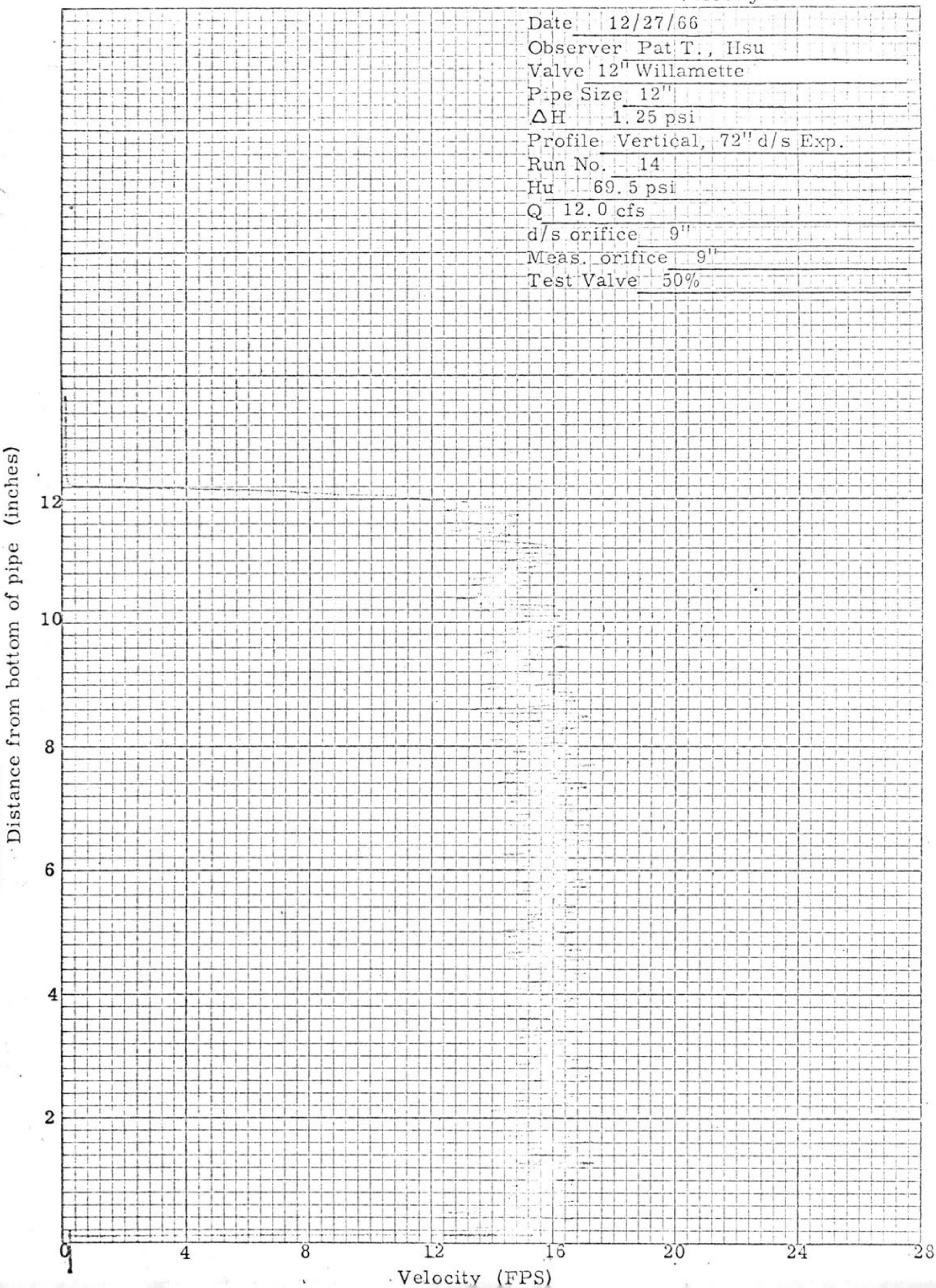



Velocity Traverse
Date 12/27/66
Observer Pat T., Hsu
Valve 12" Willamette
Pipe Size 12"
ΔH 1.25 psi
Profile Horizontal, 24" d/s Exp.
Run No. 12
Hu 69.5 psi
Q 12.0 cfs
d/s orifice 9"
Meas. orifice 9"
Test valve 50%
Distance from right side of pipe--looking downstream (inches)
0
2
4
6
8
10
12
0
4
8
12
16
20
24
28
KEUFFEL & ESSER CO.

Velocity Traverse

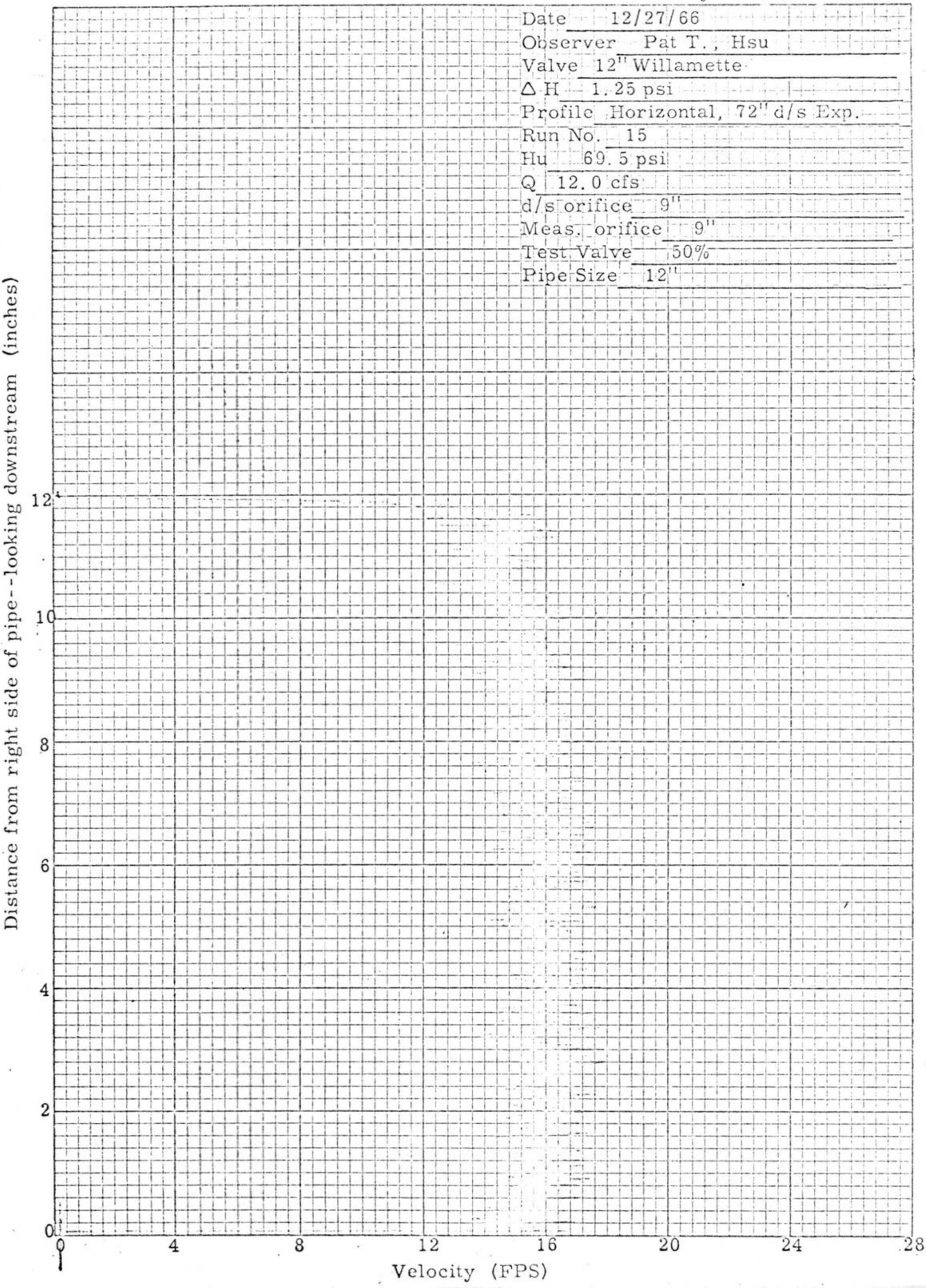


Velocity Traverse

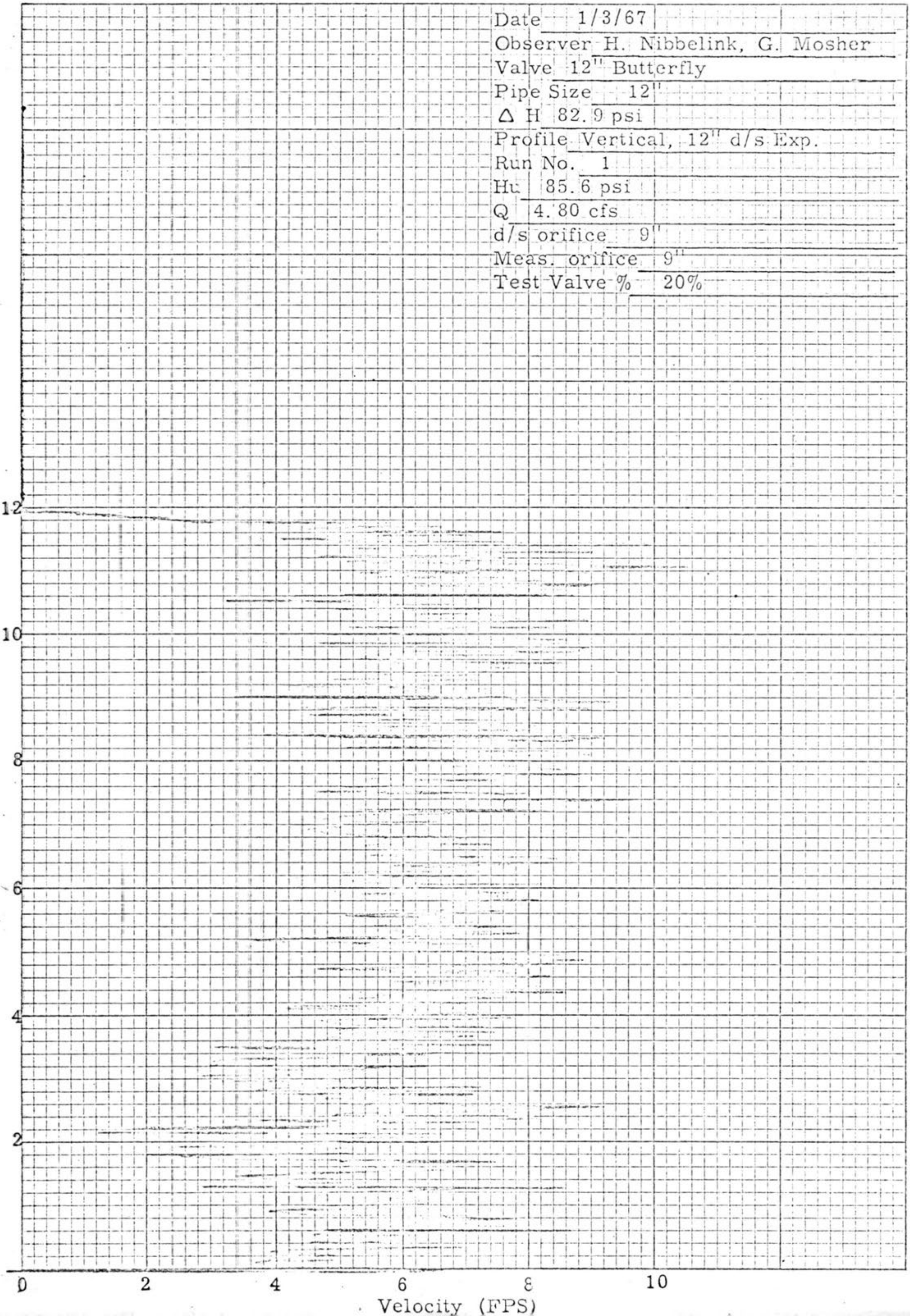


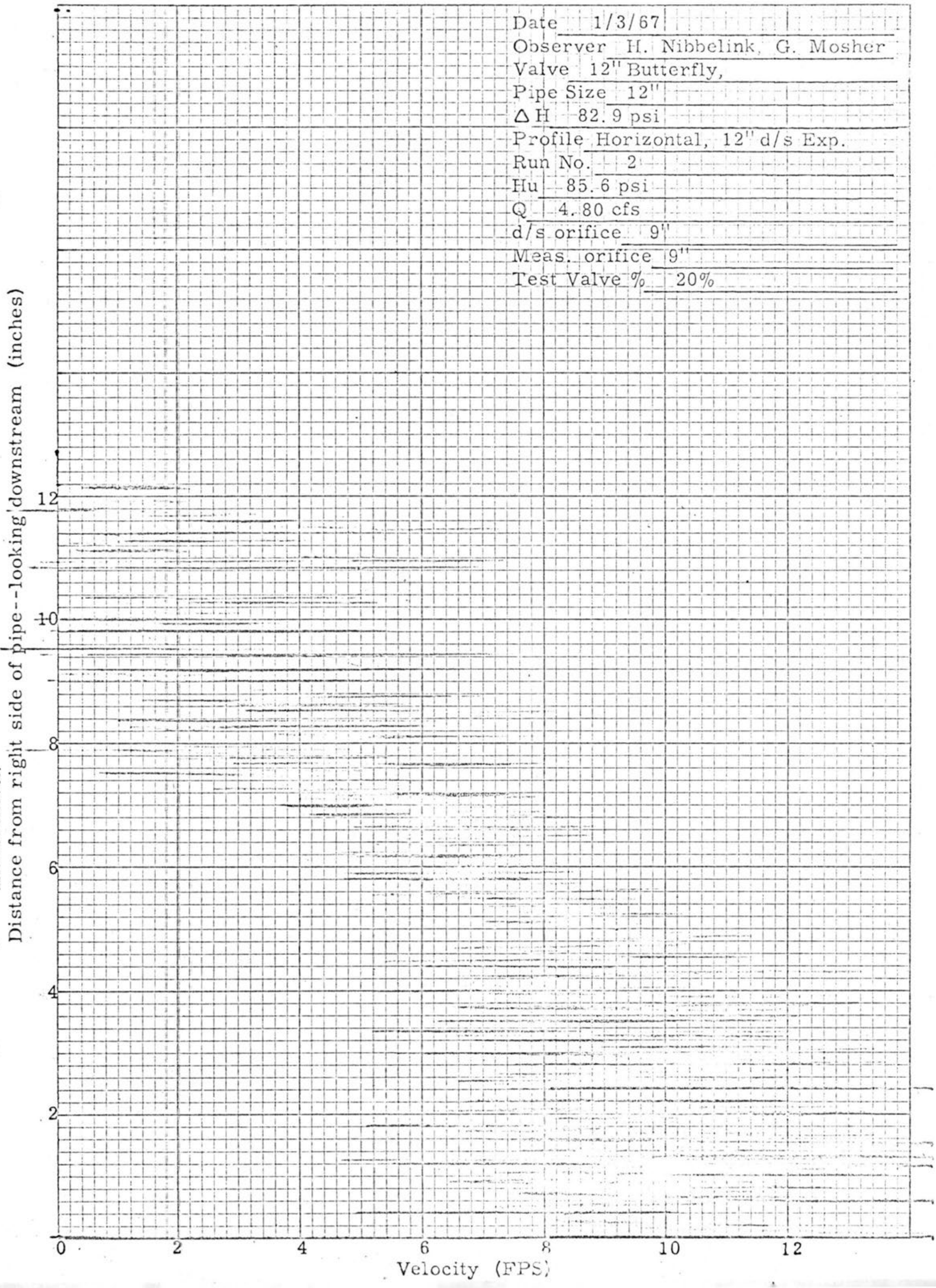
Velocity Traverse

Date 12/27/66
Observer Pat T., Hsu
Valve 12" Willamette
Δ H 1.25 psi
Profile Horizontal, 72" d/s Exp.
Run No. 15
Hu 69.5 psi
Q 12.0 cfs
d/s orifice 9"
Meas. orifice 9"
Test Valve 50%
Pipe Size 12"

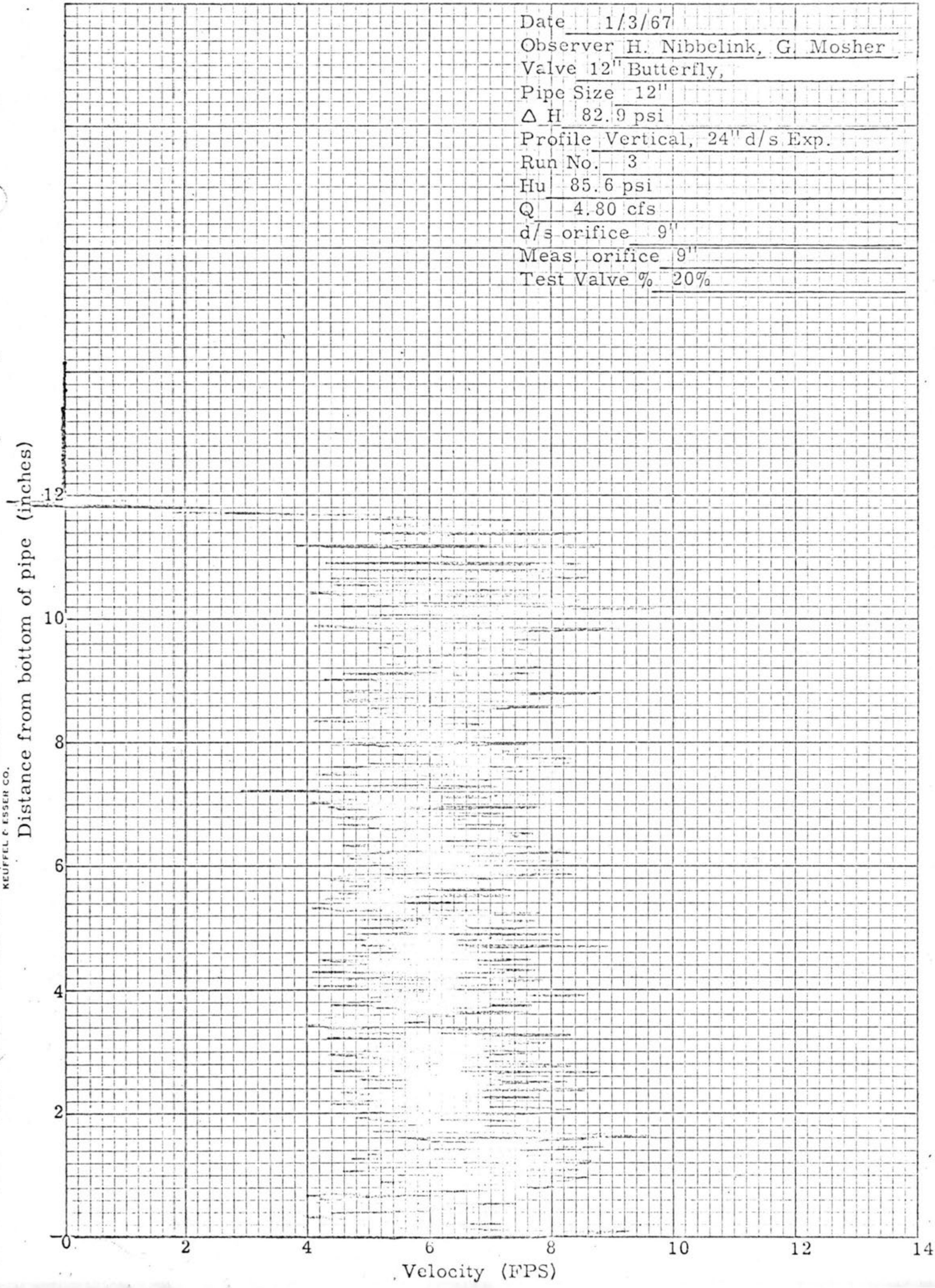


Velocity Traverse




Date 1/3/67
Observer H. Nibbelink, G. Mosher
Valve 12" Butterfly,
Pipe Size 12"
ΔH 82.9 psi
Profile Horizontal, 12" d/s Exp.
Run No. 2
Hu 85.6 psi
Q 4.80 cfs
d/s orifice 9"
Meas. orifice 9"
Test Valve % 20%
Distance from right side of pipe--looking downstream (inches)
Velocity (FPS)
0
2
4
6
8
10
12
KEUFFEL & ESSER CO.

Velocity Profile



Velocity Traverse

Date 1/3/67

Observer H. Nibbelink, G. Mosher

Valve 12" Butterfly,

Pipe size 12"

Δ H 82.9 psi

Profile Horizontal, 24" d/s Exp.

Run No. 4

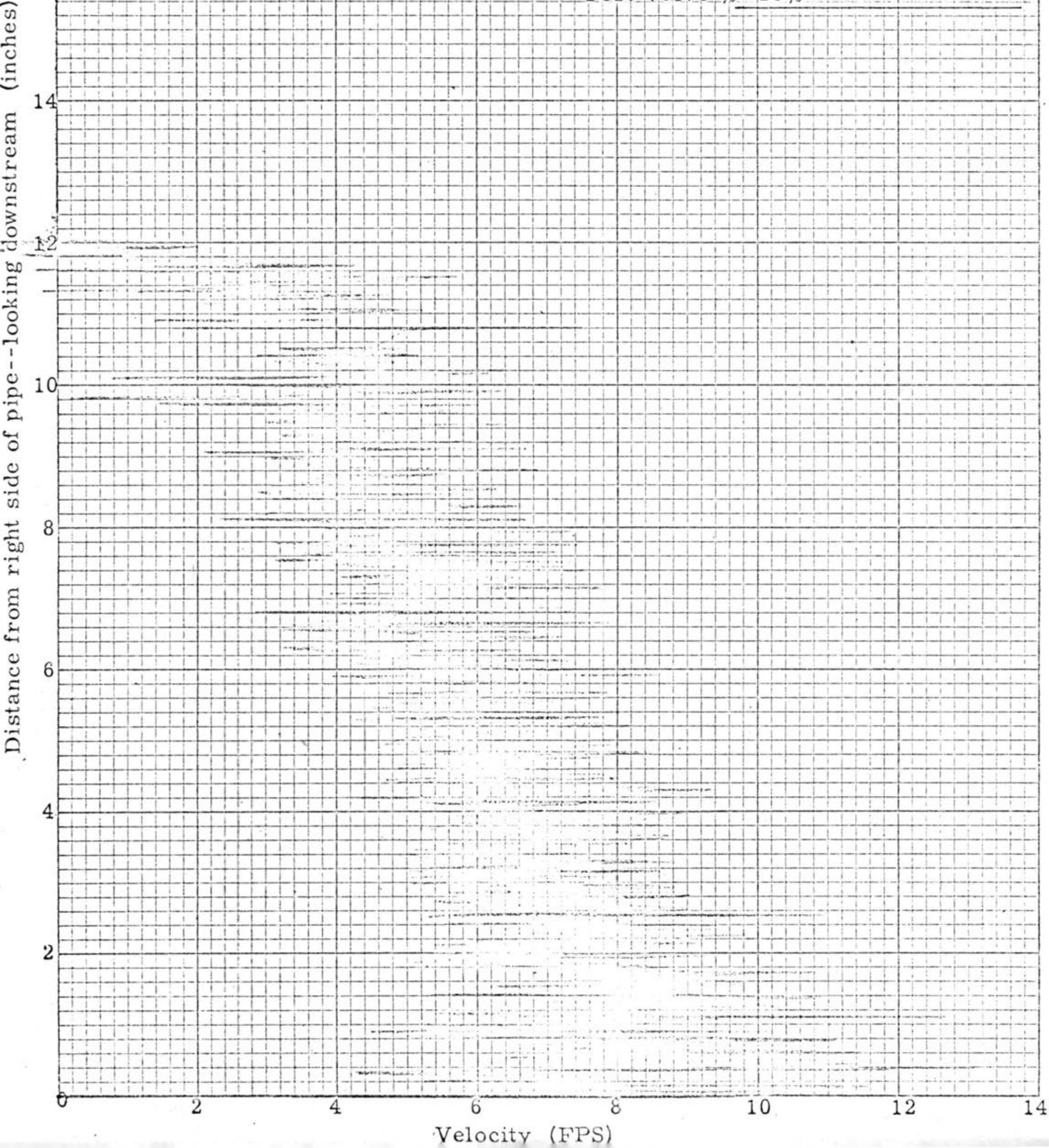
Hu 85.6 psi

Q 4.80 cfs

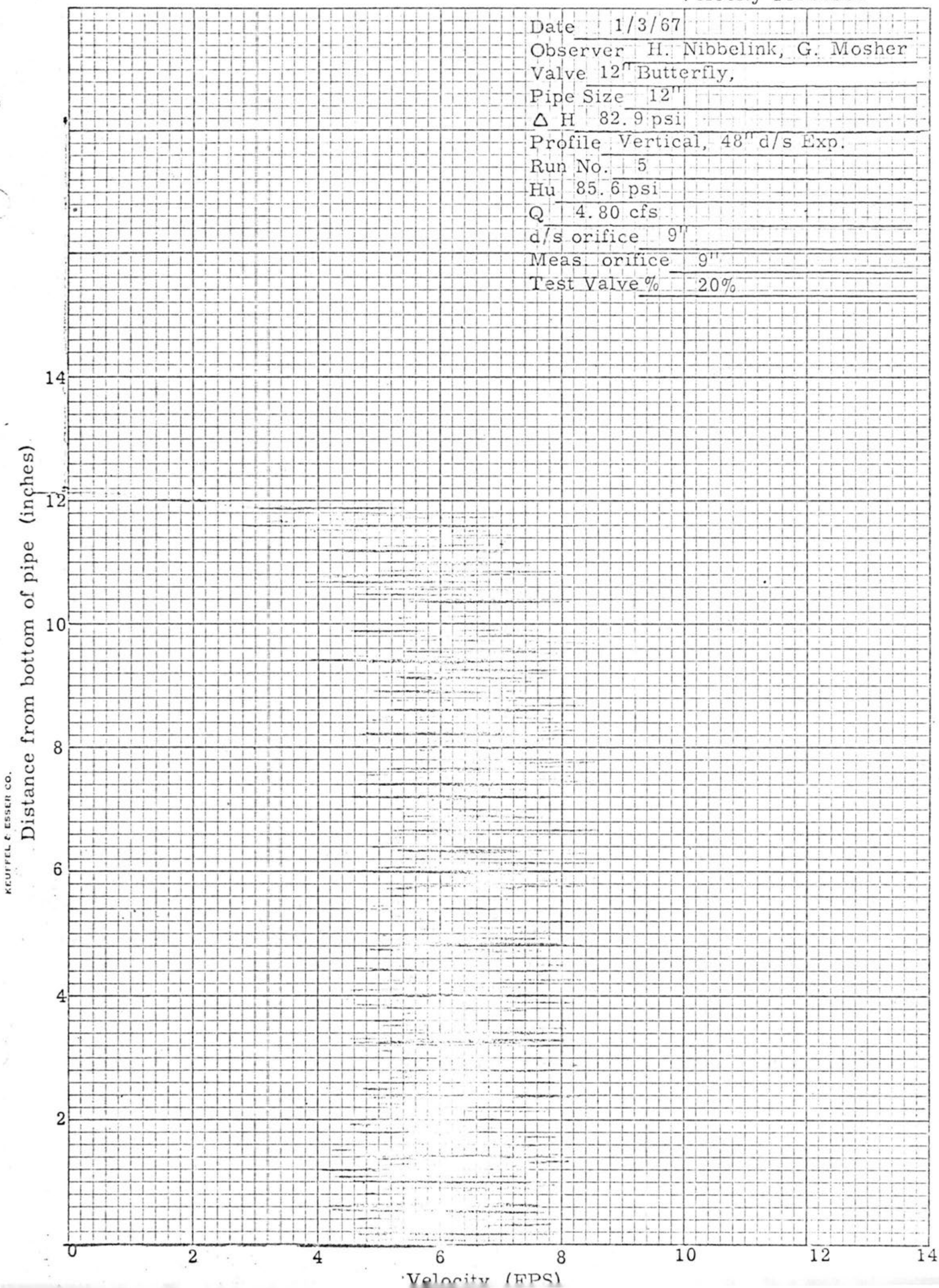
d/s orifice 9"

Meas. orifice 9"

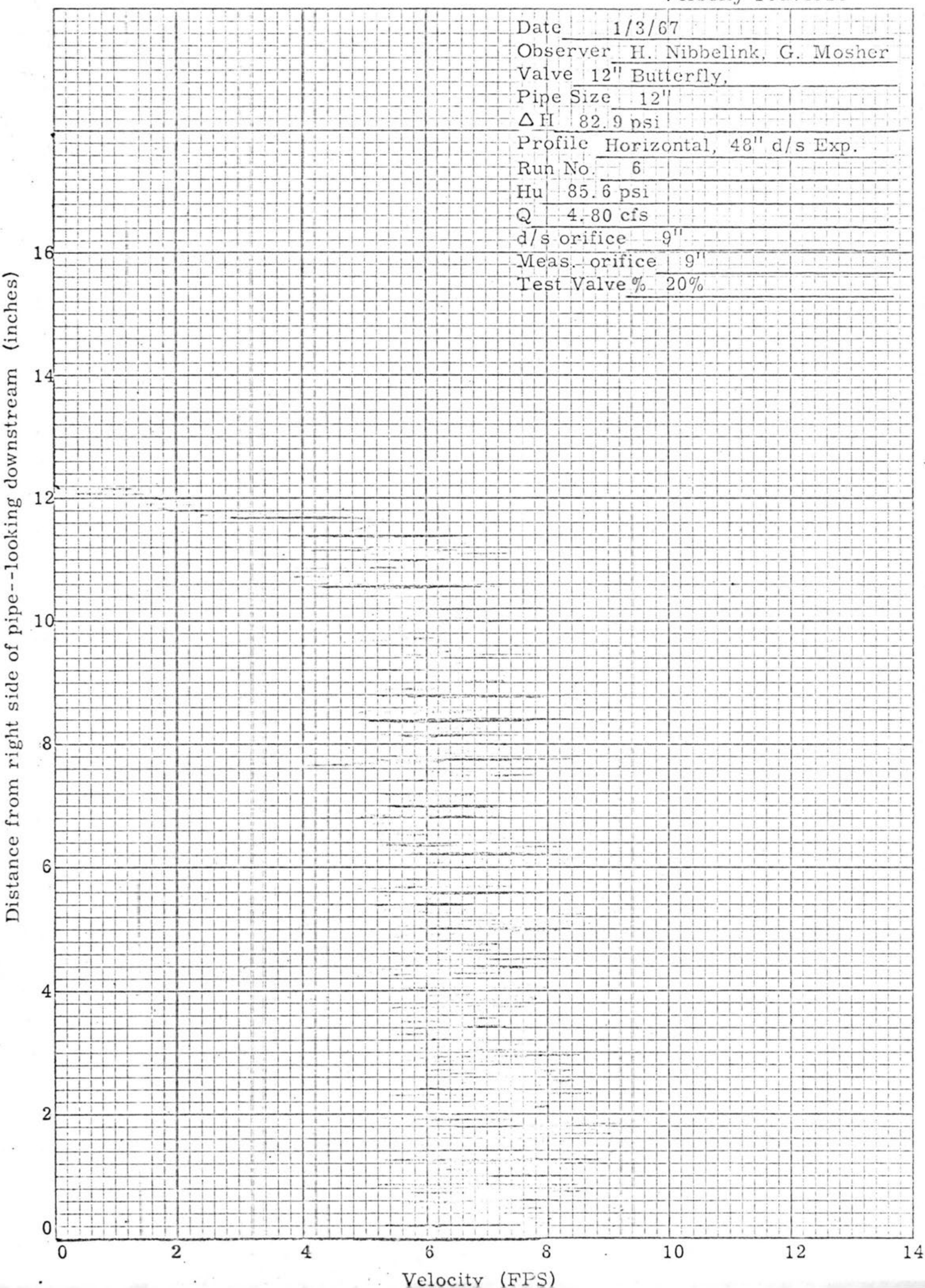
Test Valve % 20%



Velocity Traverse



Velocity Traverse



Velocity Traverse

Date 1/3/67
Observer H. Nibbelink, G. Mosher
Valve 12" Butterfly,
Pipe Size 12"
Δ H 82.9 psi
Profile Vertical, 72" d/s Exp.
Run No. 7
Hu 85.6 psi
Q 4.80 cfs
d/s orifice 9"
Meas. orifice 9"
Test Valve % 20%

Velocity Traverse

Date 1/3/67

Observer H. Nibbelink, G. Mosher

Valve 12" Butterfly,

Pipe Size 12"

Δ H 82.9 psi

Profile Horizontal, 72" d/s Exp.

Run No. 8

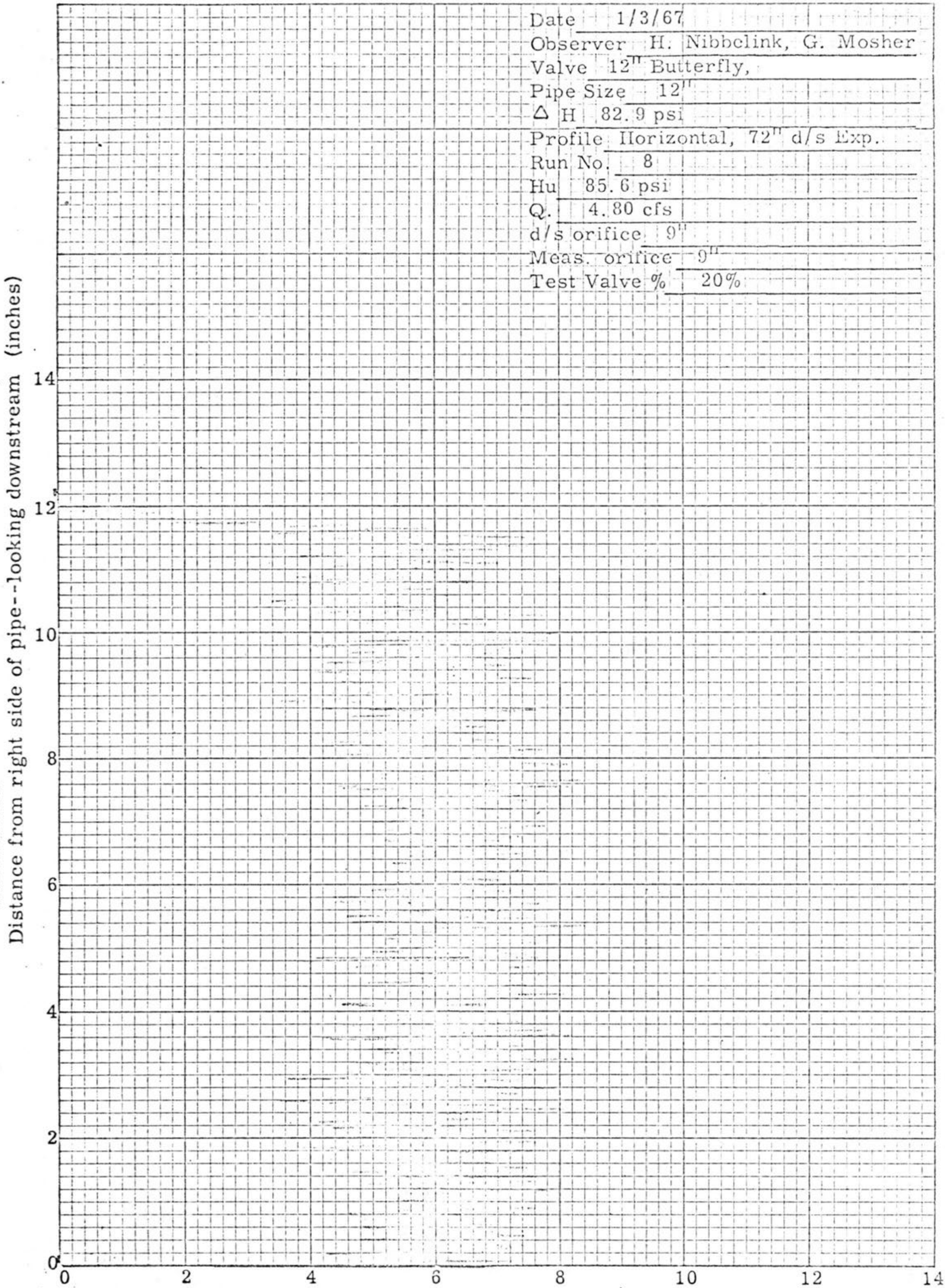
Hu 85.6 psi

Q. 4.80 cfs

d/s orifice 9"

Meas. orifice 9"

Test Valve % 20%



Velocity Traverse

Date 1/4/67

Observer H. Nibbelink, G. Mosher

Valve 12" Butterfly,

Pipe Size 12"

Δ H 10.9 psi

Profile Vertical, 12" d/s Exp.

Run No. 9

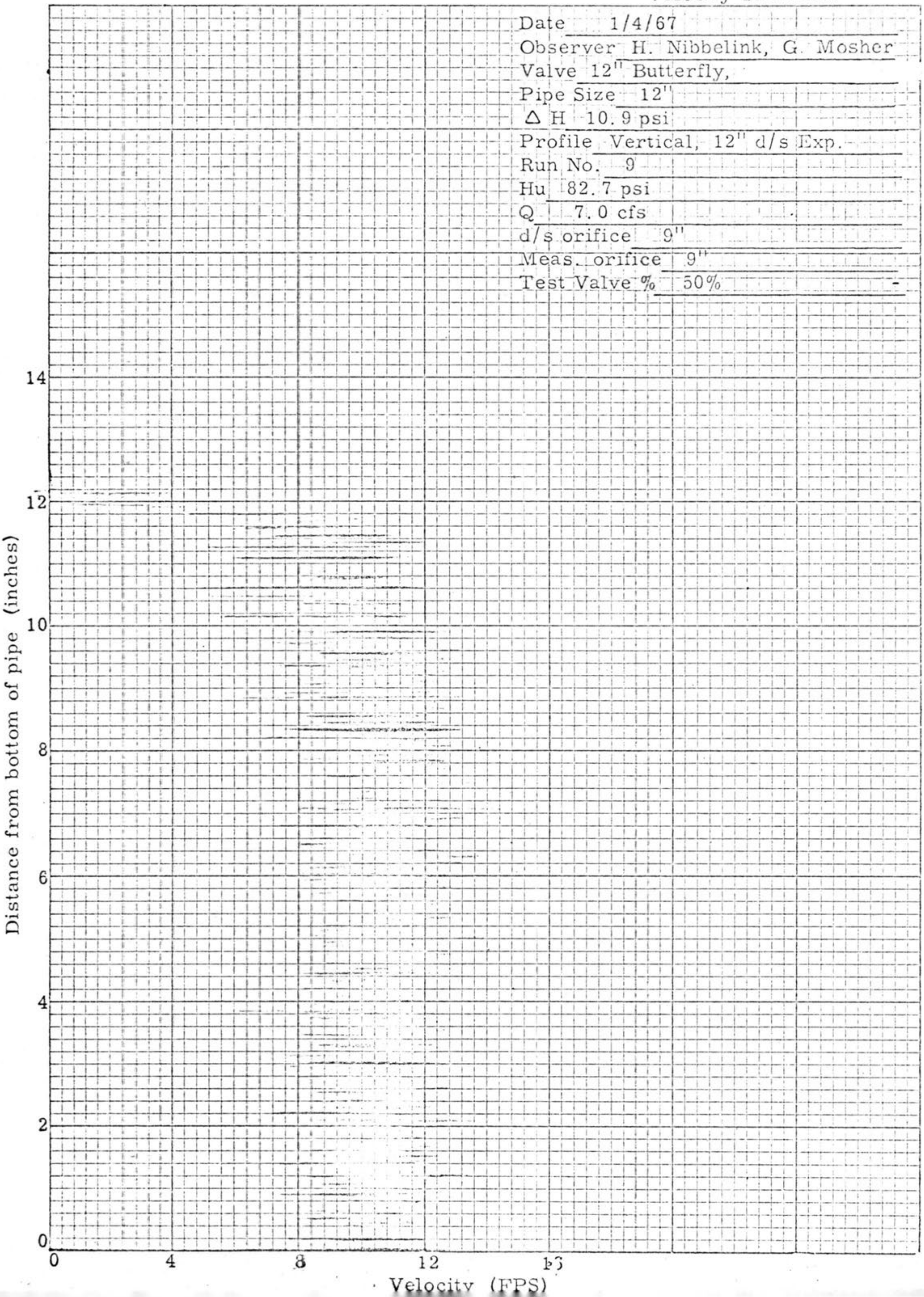
Hu 82.7 psi

Q 7.0 cfs

d/s orifice 9"

Meas. orifice 9"

Test Valve % 50%



Velocity Traverse

Date 1/4/67

Observer H. Nibbelink, G. Mosher

Valve 12" Butterfly,

Pipe Size 12"

Δ H 10.9 psi

Profile Horizontal, 12" d/s Exp.

Run No. 10

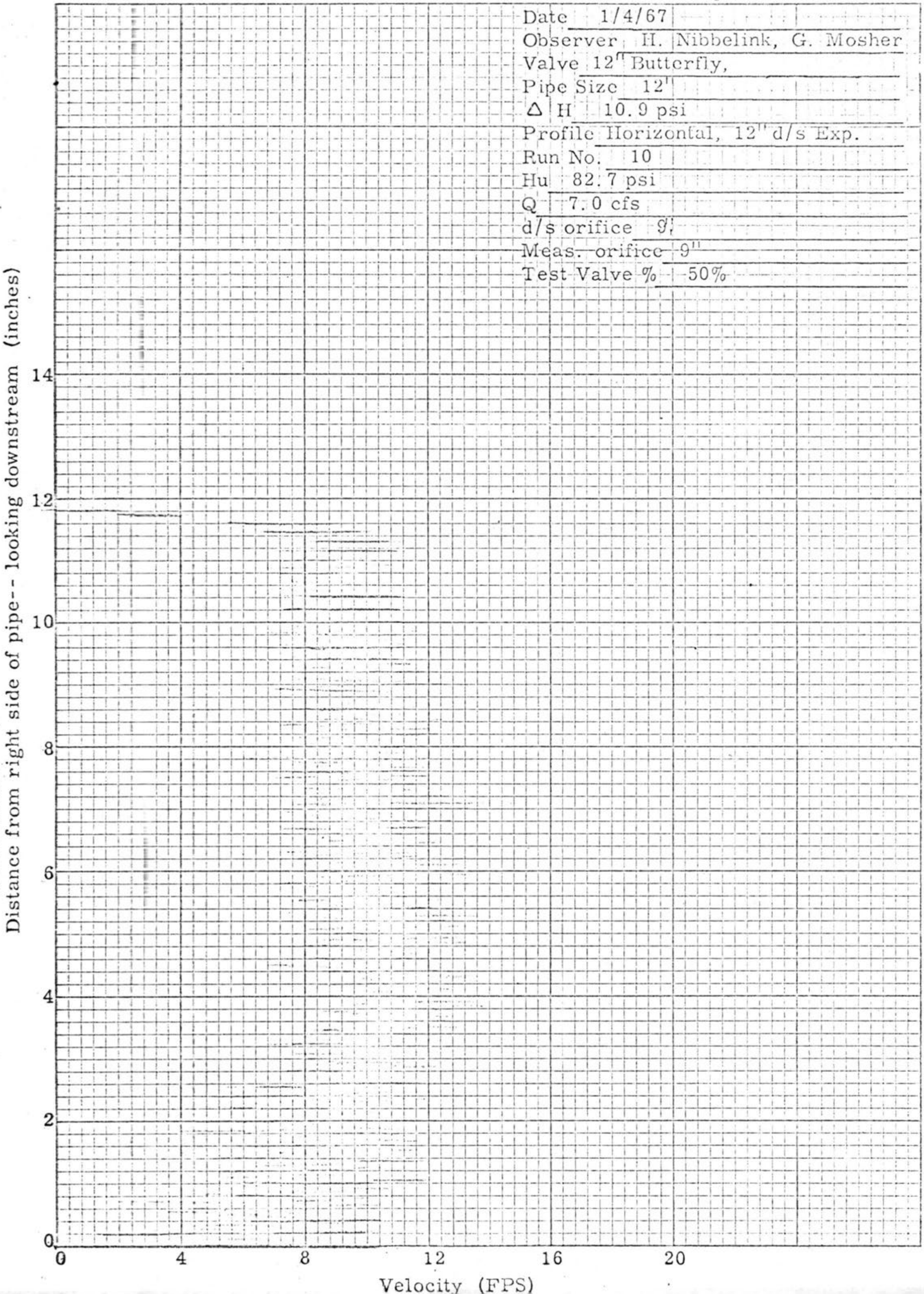
Hu 82.7 psi

Q 7.0 cfs

d/s orifice 9"

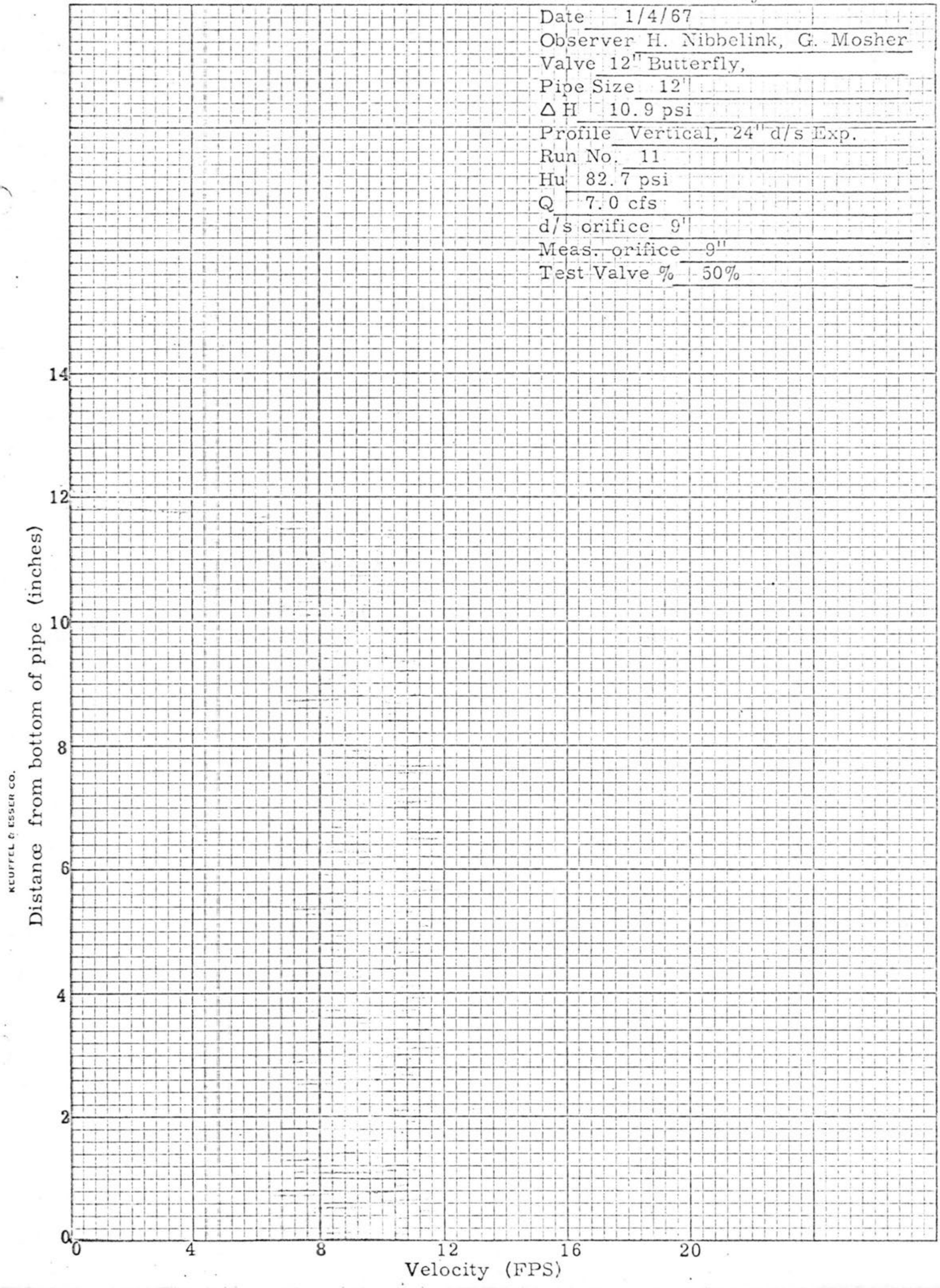
Meas. orifice 9"

Test Valve % 50%



Velocity Traverse

Date 1/4/67
Observer H. Nibbelink, G. Mosher
Valve 12" Butterfly,
Pipe Size 12"
Δ H 10.9 psi
Profile Vertical, 24" d/s Exp.
Run No. 11
Hu 82.7 psi
Q 7.0 cfs
d/s orifice 9"
Meas. orifice 9"
Test Valve % 50%



Velocity Traverse

Date 1/4/67
Observer H. Nibbelink, G. Mosher
Valve 12 Butterfly,
Pipe Size 12"
Δ H 10.9 psi
Profile Horizontal, 24" d/s Exp.
Run No. 12
Hu 82.7 psi
Q 7.0 cfs
d/s orifice 9"
Meas. orifice 9"
Test valve % 50%

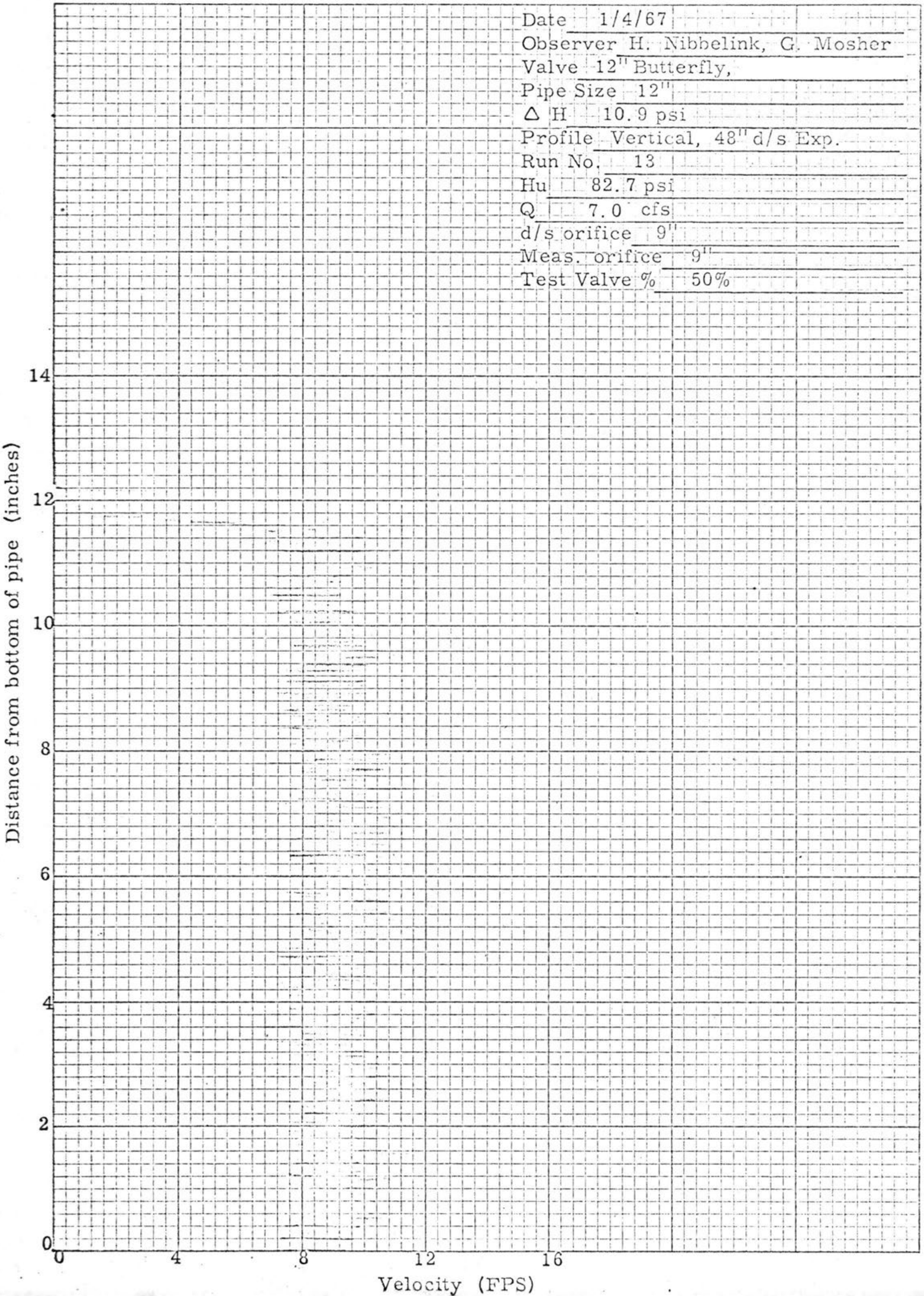
Distance from right side of pipe--looking downstream (inches)

14
12
10
8
6
4
2
0

0 4 8 12 16 20

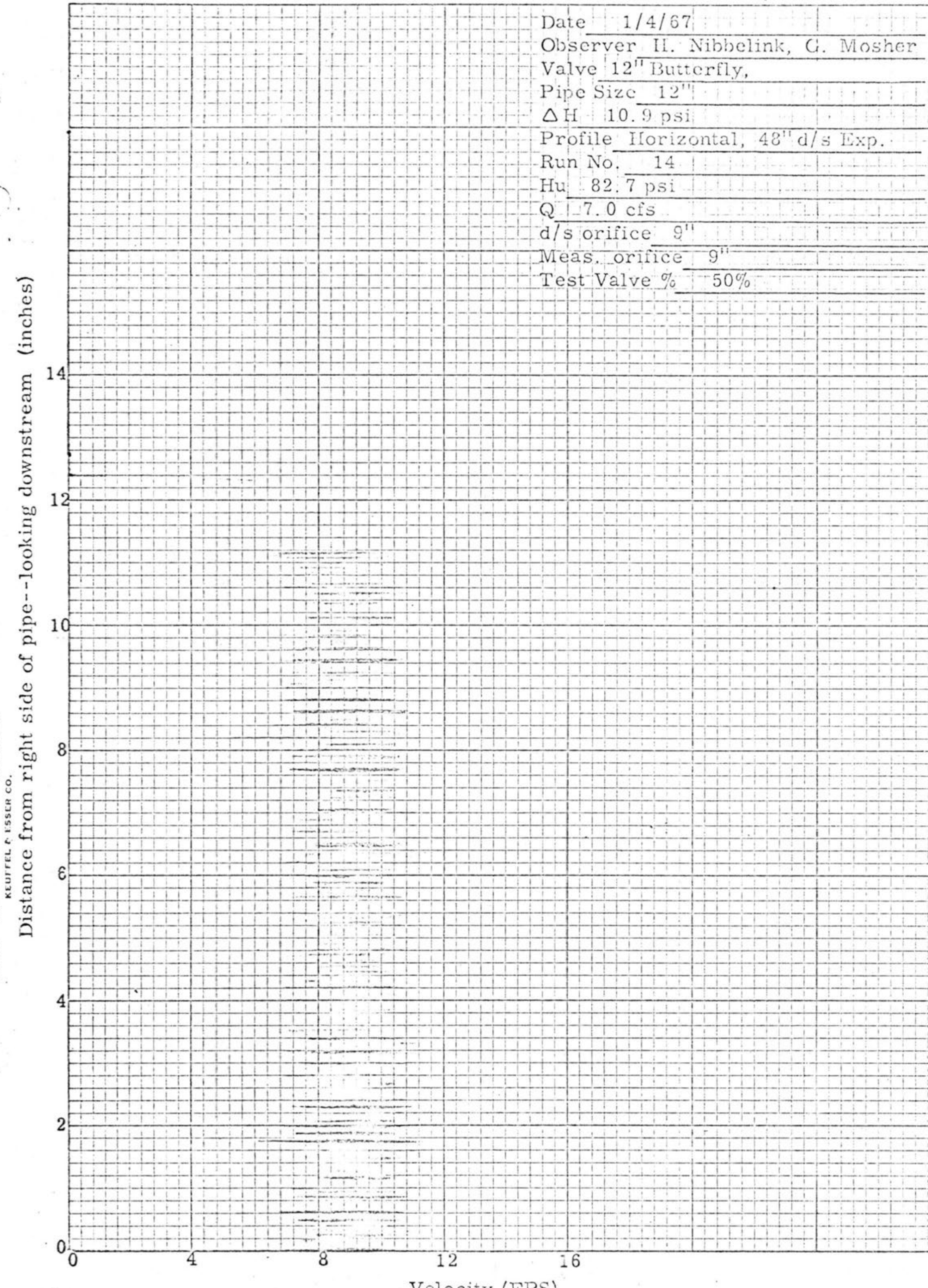
Velocity (FPS)

Date 1/4/67
Observer H. Nibbelink, G. Mosher
Valve 12" Butterfly,
Pipe Size 12"
Δ H 10.9 psi
Profile Vertical, 48" d/s Exp.
Run No. 13
Hu 82.7 psi
Q 7.0 cfs
d/s orifice 9"
Meas. orifice 9"
Test Valve % 50%



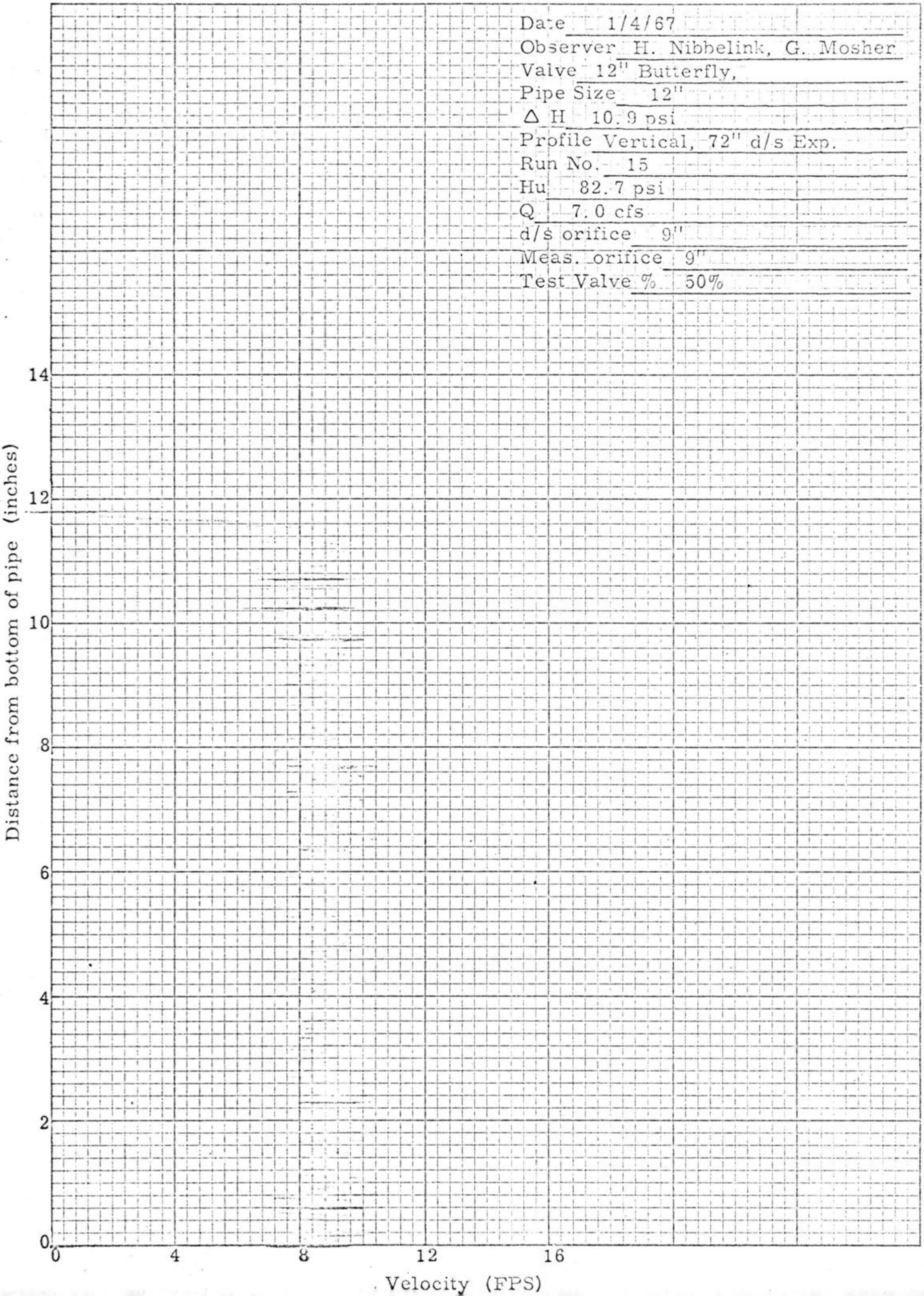
Velocity Traverse

Date 1/4/67
Observer H. Nibbelink, G. Mosher
Valve 12" Butterfly,
Pipe Size 12"
ΔH 10.9 psi
Profile Horizontal, 48" d/s Exp.
Run No. 14
Hu 82.7 psi
Q 7.0 cfs
d/s orifice 9"
Meas. orifice 9"
Test Valve % 50%



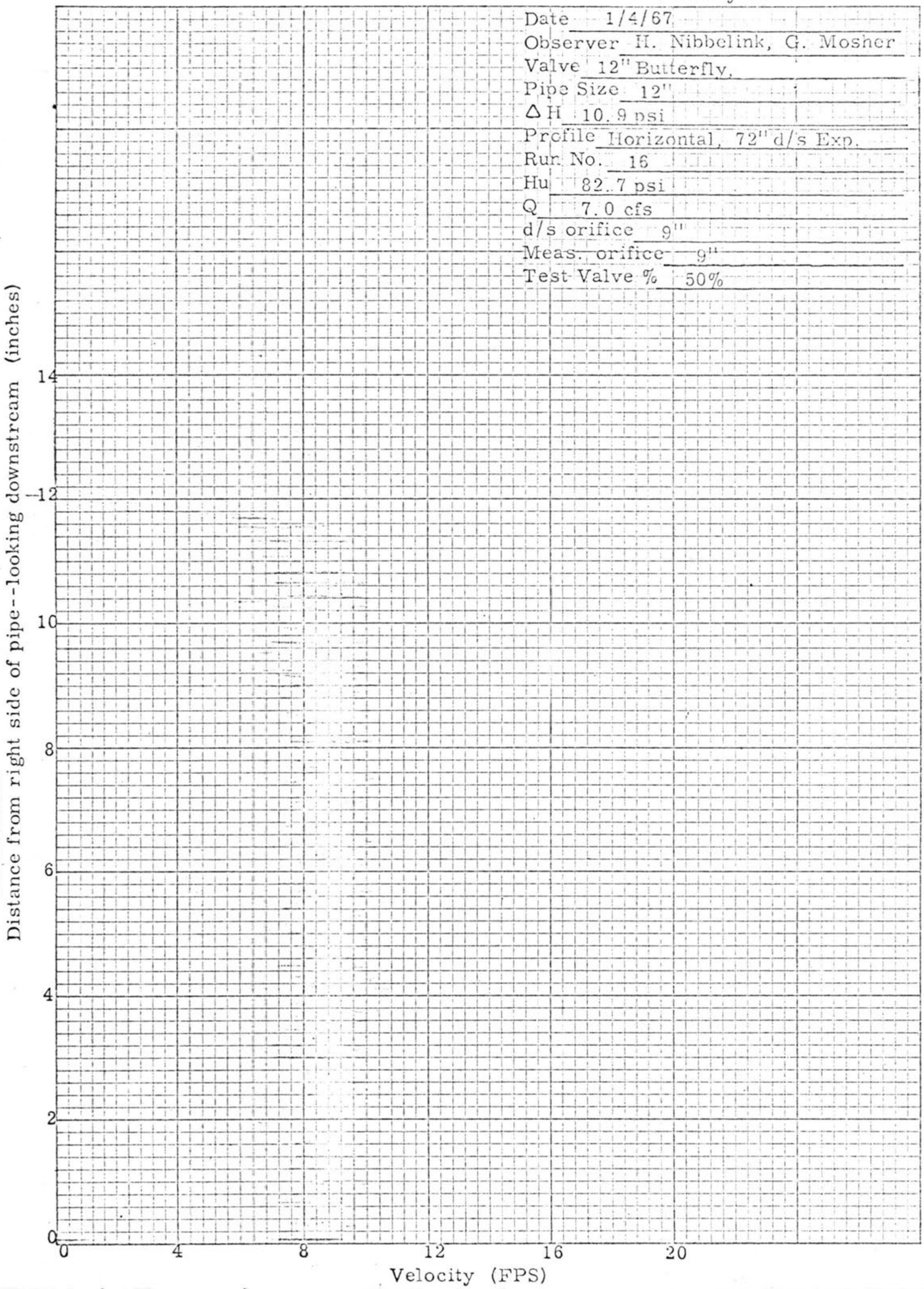
Velocity Traverse

Date 1/4/67
Observer H. Nibbelink, G. Mosher
Valve 12" Butterfly,
Pipe Size 12"
Δ H 10.9 psi
Profile Vertical, 72" d/s Exp.
Run No. 15
Hu 82.7 psi
Q 7.0 cfs
d/s orifice 9"
Meas. orifice 9"
Test Valve % 50%



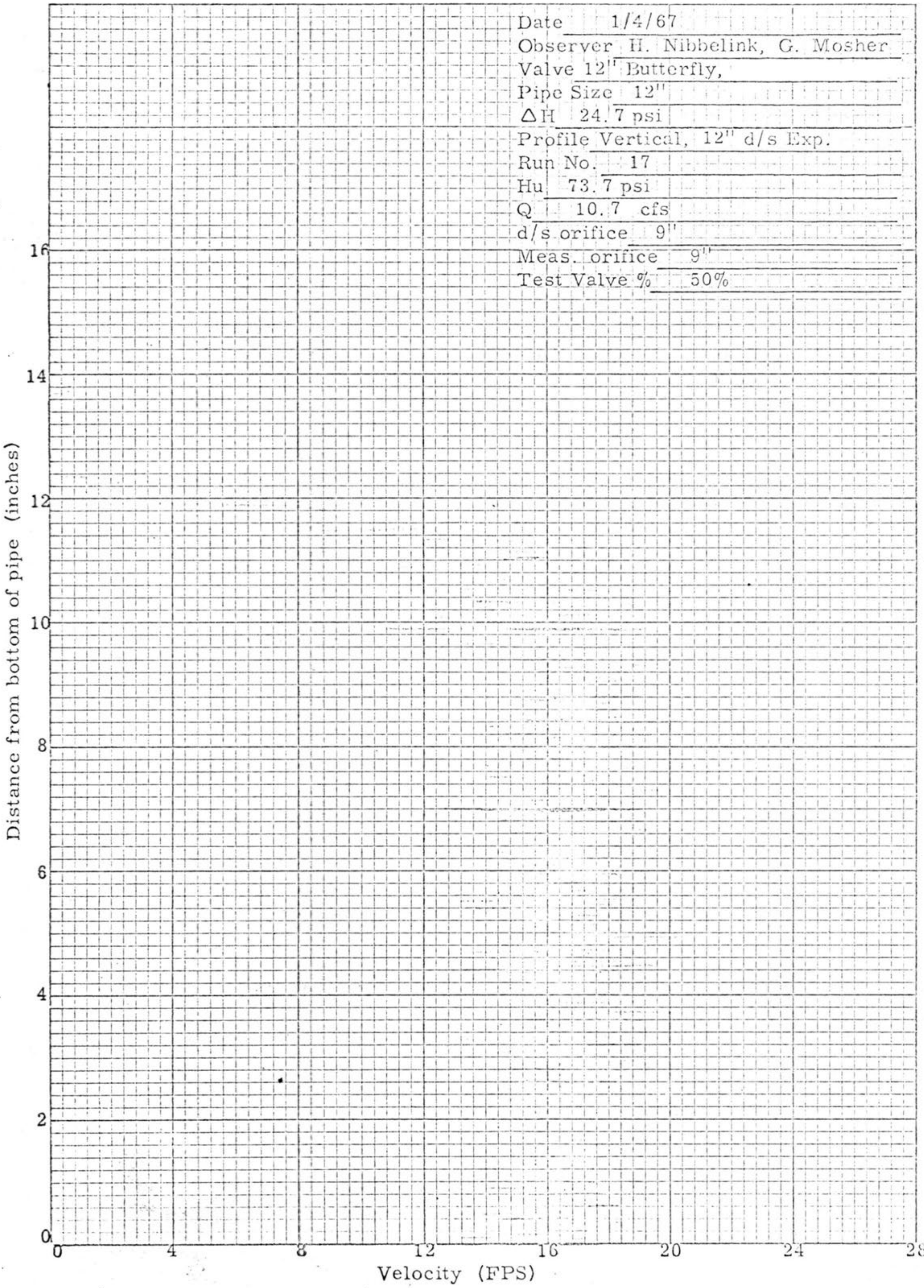
Velocity Traverse

Date 1/4/67
Observer H. Nibbelink, G. Mosher
Valve 12" Butterfly
Pipe Size 12"
ΔH 10.9 psi
Profile Horizontal, 72" d/s Exp.
Run No. 16
Hu 82.7 psi
Q 7.0 cfs
d/s orifice 9"
Meas. orifice 9"
Test Valve % 50%



Velocity Traverse

Date 1/4/67
Observer H. Nibbelink, G. Mosher
Valve 12" Butterfly,
Pipe Size 12"
ΔH 24.7 psi
Profile Vertical, 12" d/s Exp.
Run No. 17
Hu 73.7 psi
Q 10.7 cfs
d/s orifice 9"
Meas. orifice 9"
Test Valve % 50%



Velocity Traverse

Date 1/4/67

Observer H. Nibbelink, G. Mosher

Valve 12" Butterfly,

Pipe Size 12"

Δ H 24.7 psi

Profile Horizontal, 12" d/s Exp.

Run No. 18

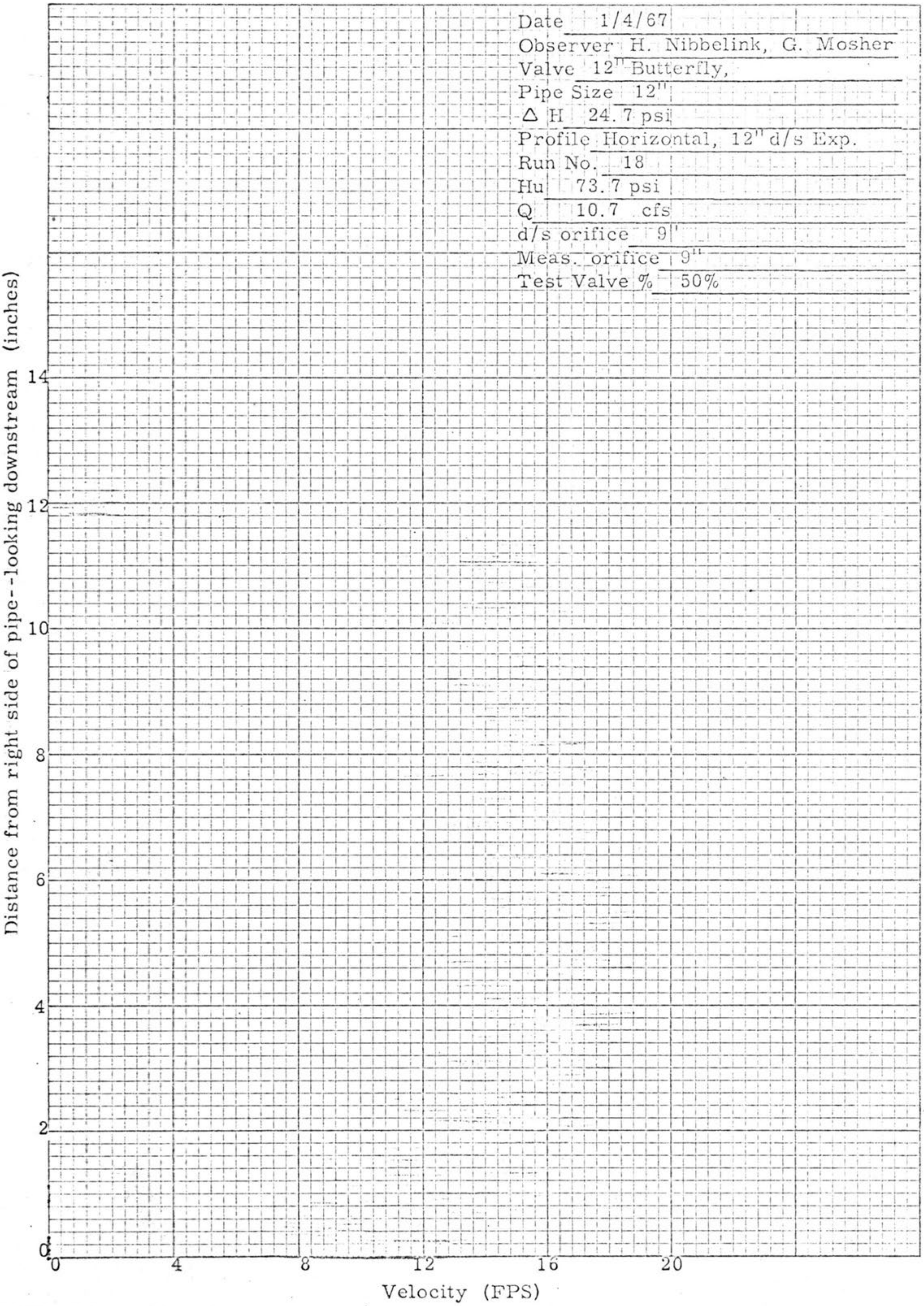
Hu 73.7 psi

Q 10.7 cfs

d/s orifice 9"

Meas. orifice 9"

Test Valve % 50%



Velocity Traverse

Date 1/4/67

Observer H. Nibbelink, G. Mosher

Valve 12" Butterfly,

Pipe Size 12"

ΔH 24.7 psi

Profile Vertical, 24" d/s Exp.

Run No. 19

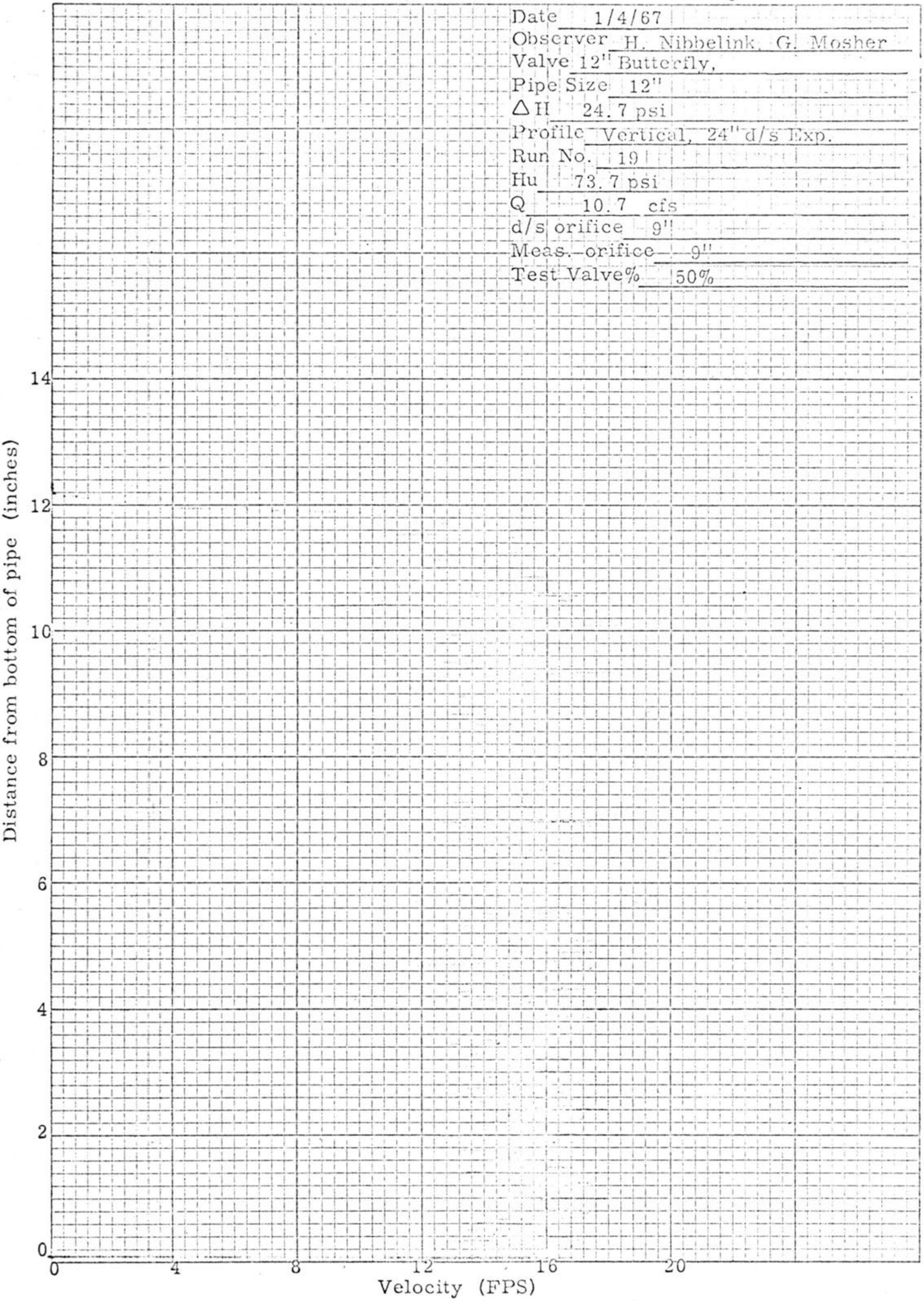
Hu 73.7 psi

Q 10.7 cfs

d/s orifice 9"

Meas. orifice 9"

Test Valve% 50%



Velocity Traverse

Date 1/4/67

Observer H. Nibbelink, G. Mosher

Valve 12" Butterfly

Pipe Size 12"

Δ H 24.7 psi

Profile Horizontal, 24" d/s Exp.

Run No. 20

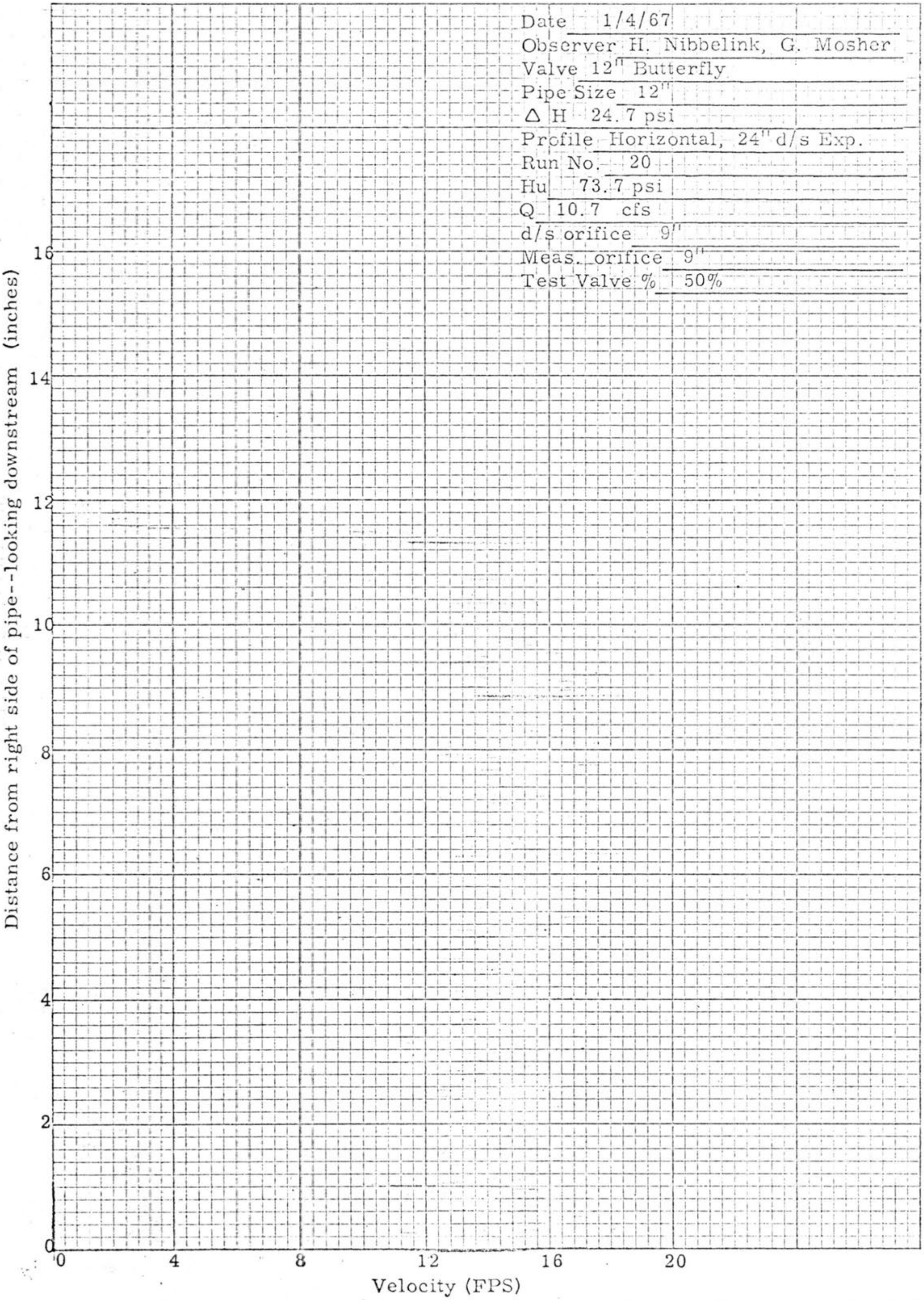
Hu 73.7 psi

Q 10.7 cfs

d/s orifice 9"

Meas. orifice 9"

Test Valve % 50%



Velocity Traverse

Date 1/4/67
Observer H. Nibbelink, G. Mosher
Valve 12" Butterfly
Pipe Size 12"
Δ H 24.7 psi
Profile Vertical, 48" d/s Exp.
Run No. 21
Hu 73.7 psi
Q 10.7 cfs
d/s orifice 9"
Meas. orifice 9"
Test Valve % 50%

Velocity Traverse

Date 1/4/67

Observer H. Nibbelink, G. Mosher

Valve 12" Butterfly

Pipe Size 12"

Δ H 24.7 psi

Profile Horizontal, 48" d/s Exp.

Run No. 22

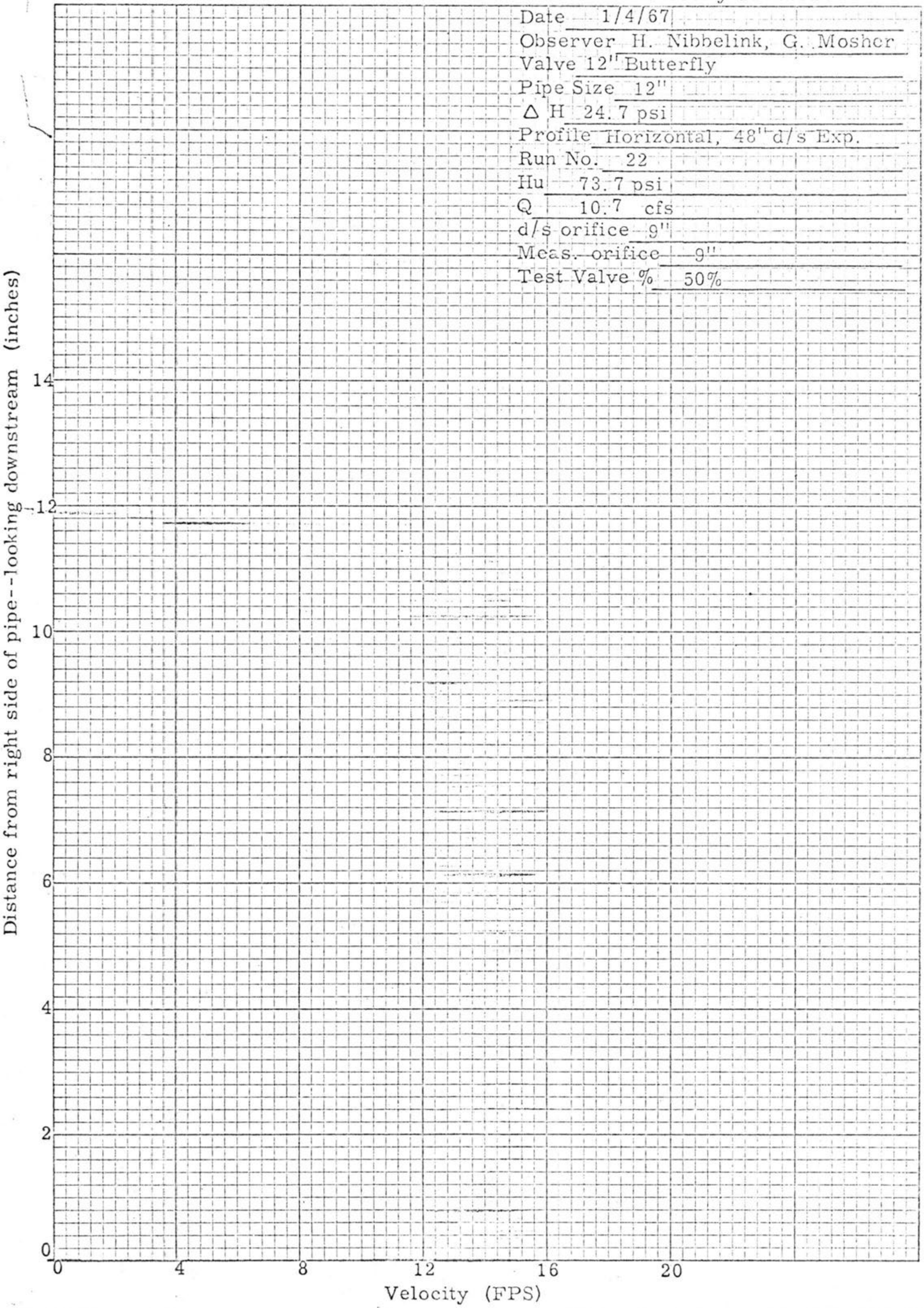
Hu 73.7 psi

Q 10.7 cfs

d/s orifice 9"

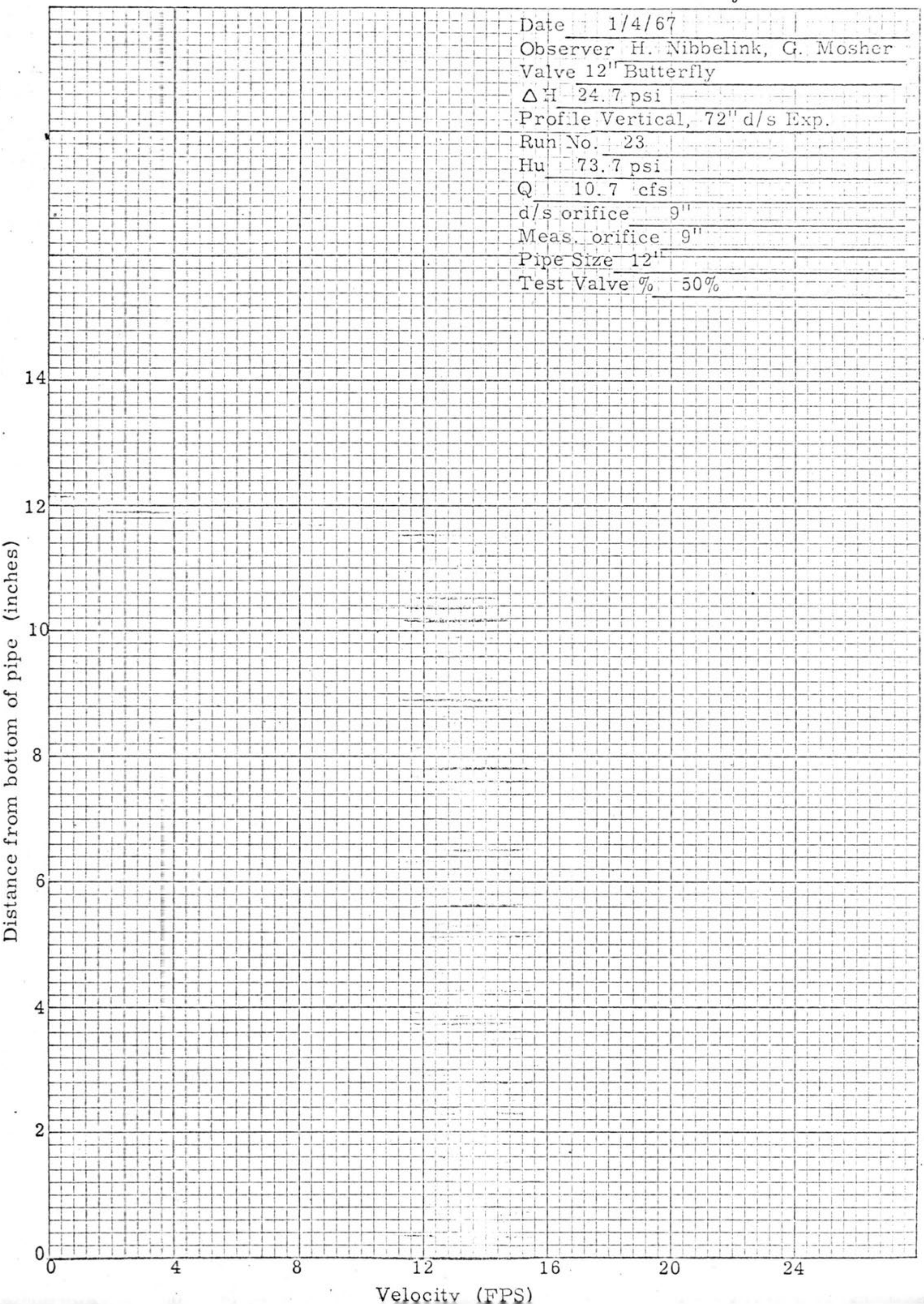
Meas. orifice 9"

Test Valve % 50%



Velocity Traverse

Date 1/4/67
Observer H. Nibbelink, G. Mosher
Valve 12" Butterfly
ΔH 24.7 psi
Profile Vertical, 72" d/s Exp.
Run No. 23
Hu 73.7 psi
Q 10.7 cfs
d/s orifice 9"
Meas. orifice 9"
Pipe Size 12"
Test Valve % 50%



Velocity Traverse

Date 1/4/67

Observer Nibbelink, G. Mosher

Valve 12" Butterfly

Pipe Size 12"

Δ H 24.7 psi

Profile Horizontal, 72" ds Exp.

Run No. 24

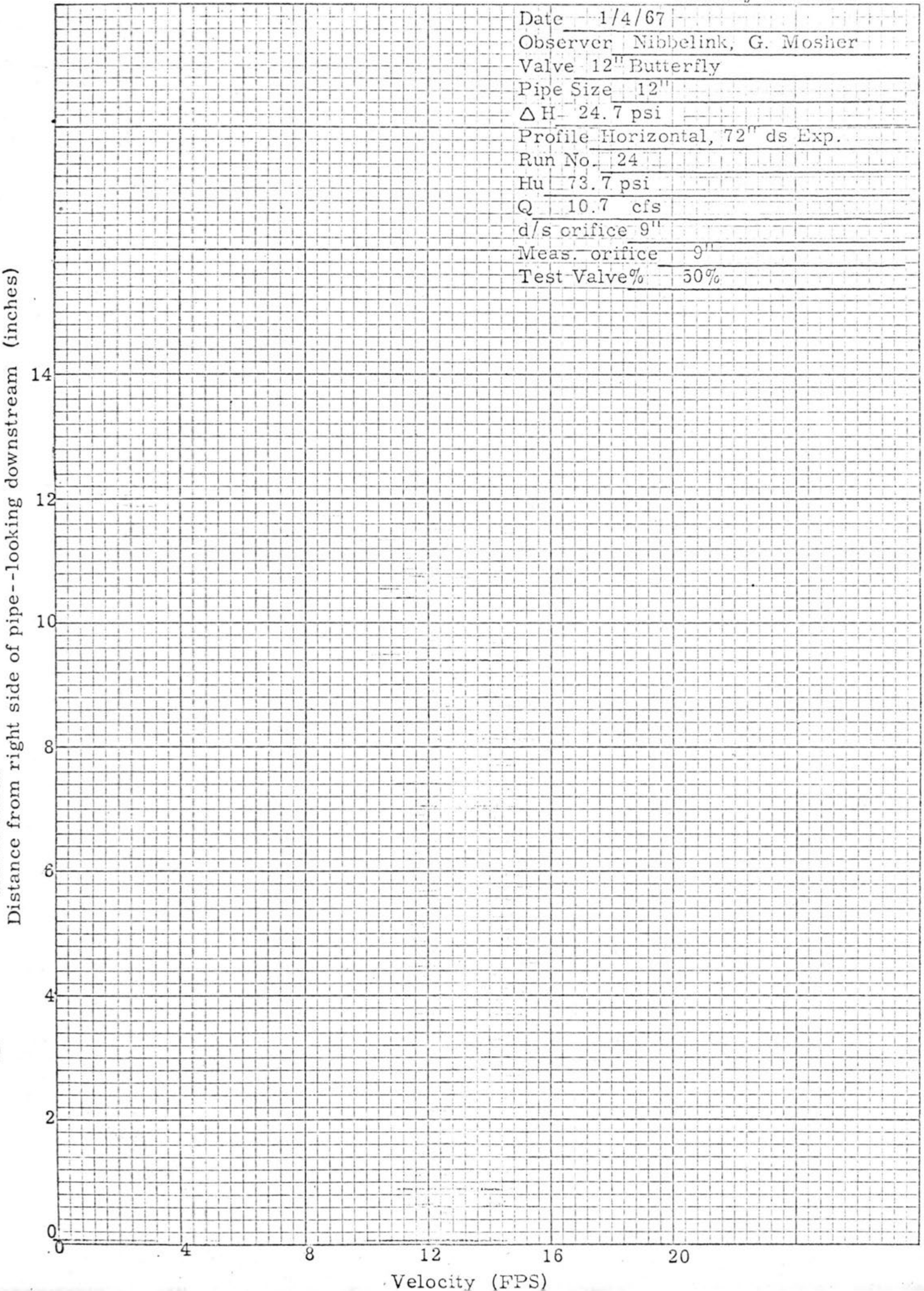
Hu 73.7 psi

Q 10.7 cfs

d/s orifice 9"

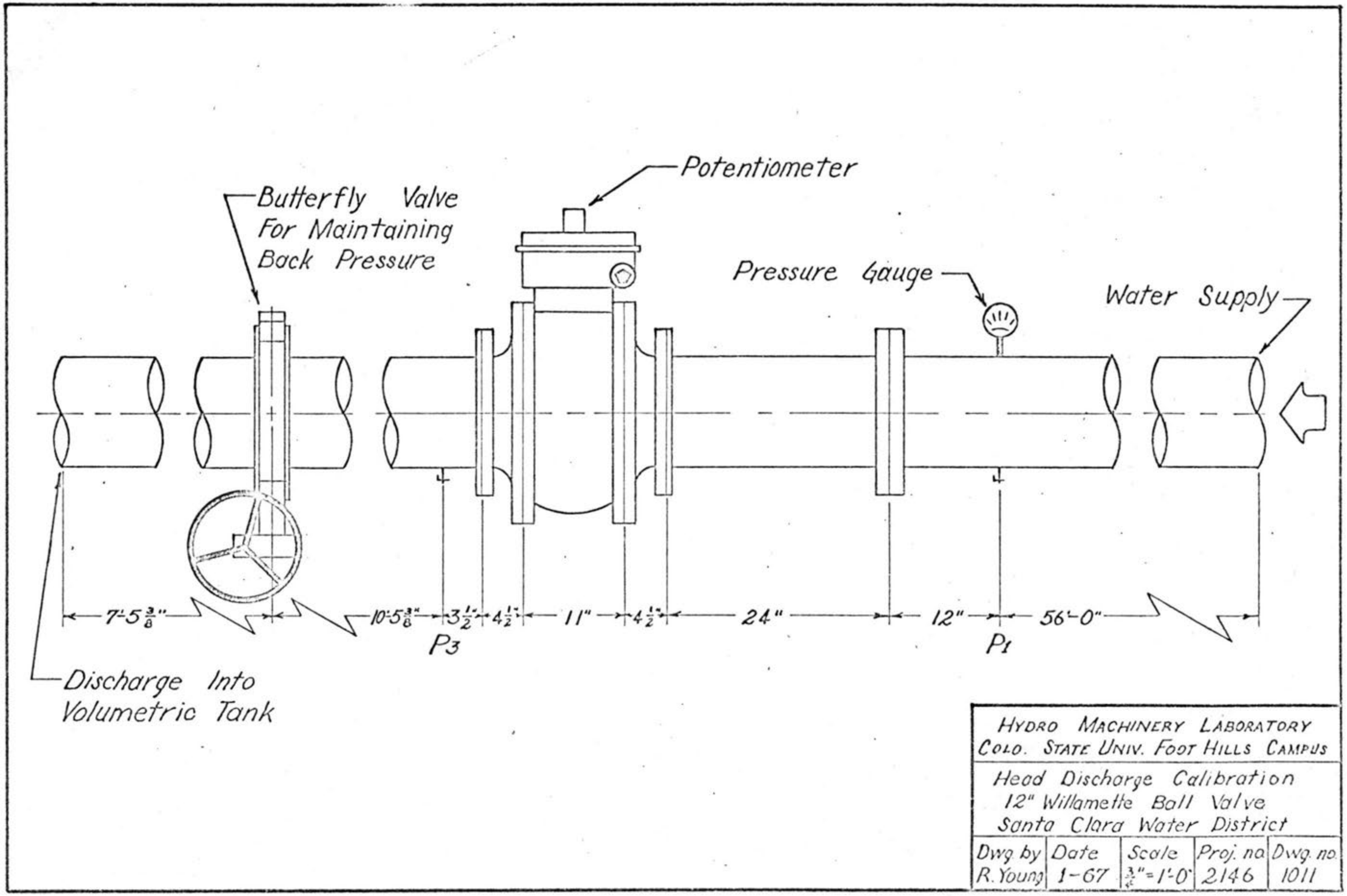
Meas. orifice 9"

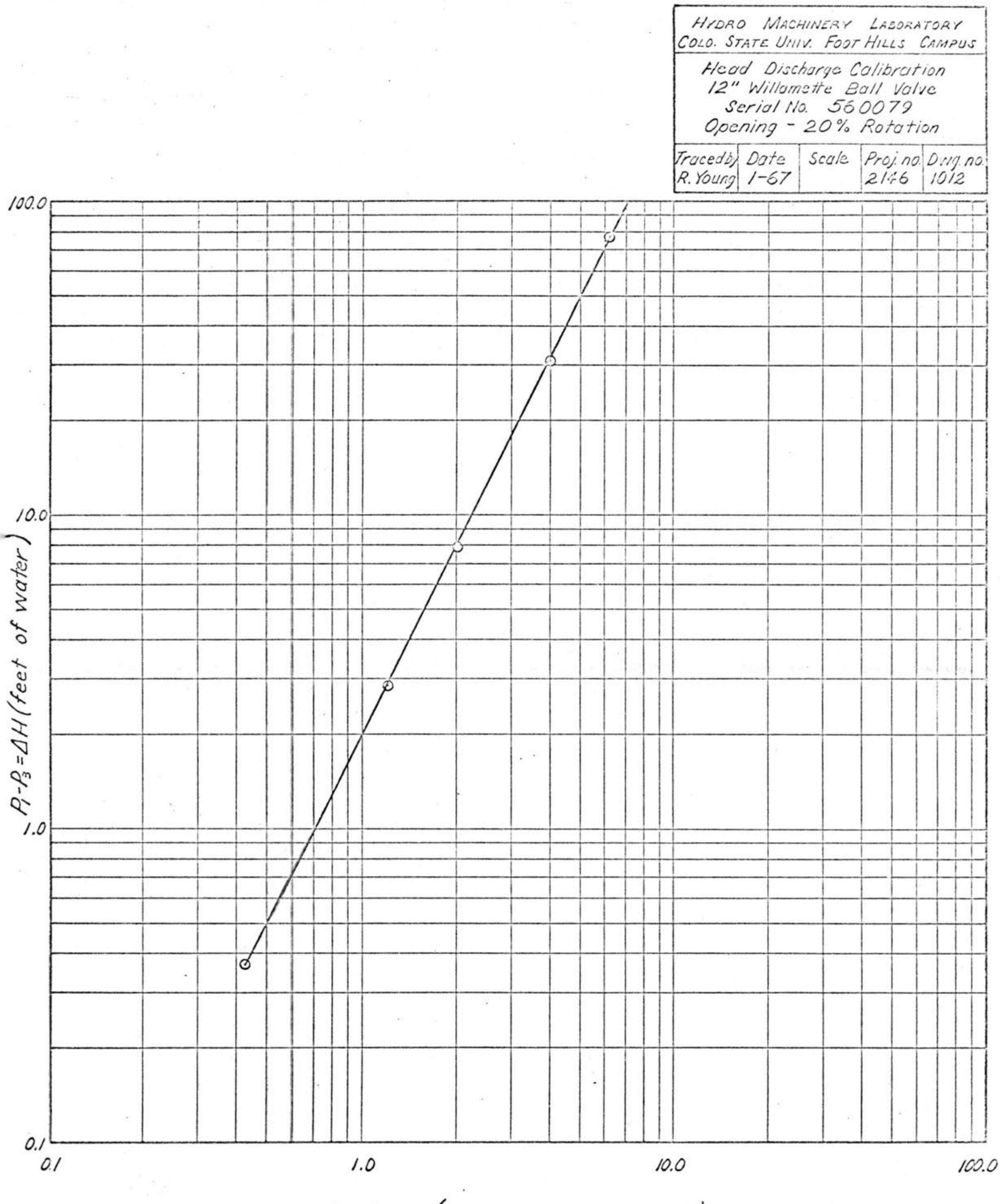
Test Valve% 50%

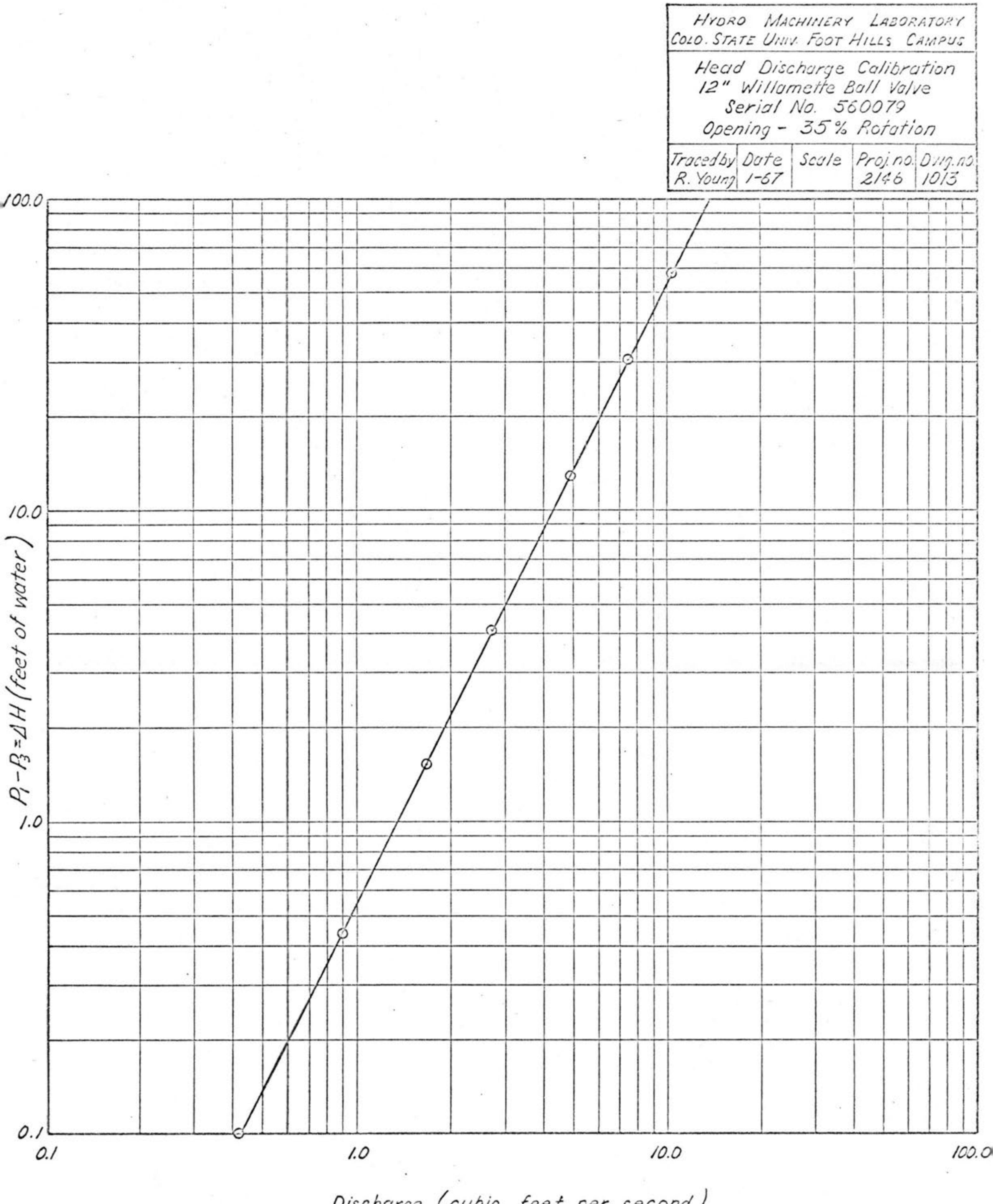


Appendix D	Q vs ΔH Calibration
(Volumetric Test Stand)

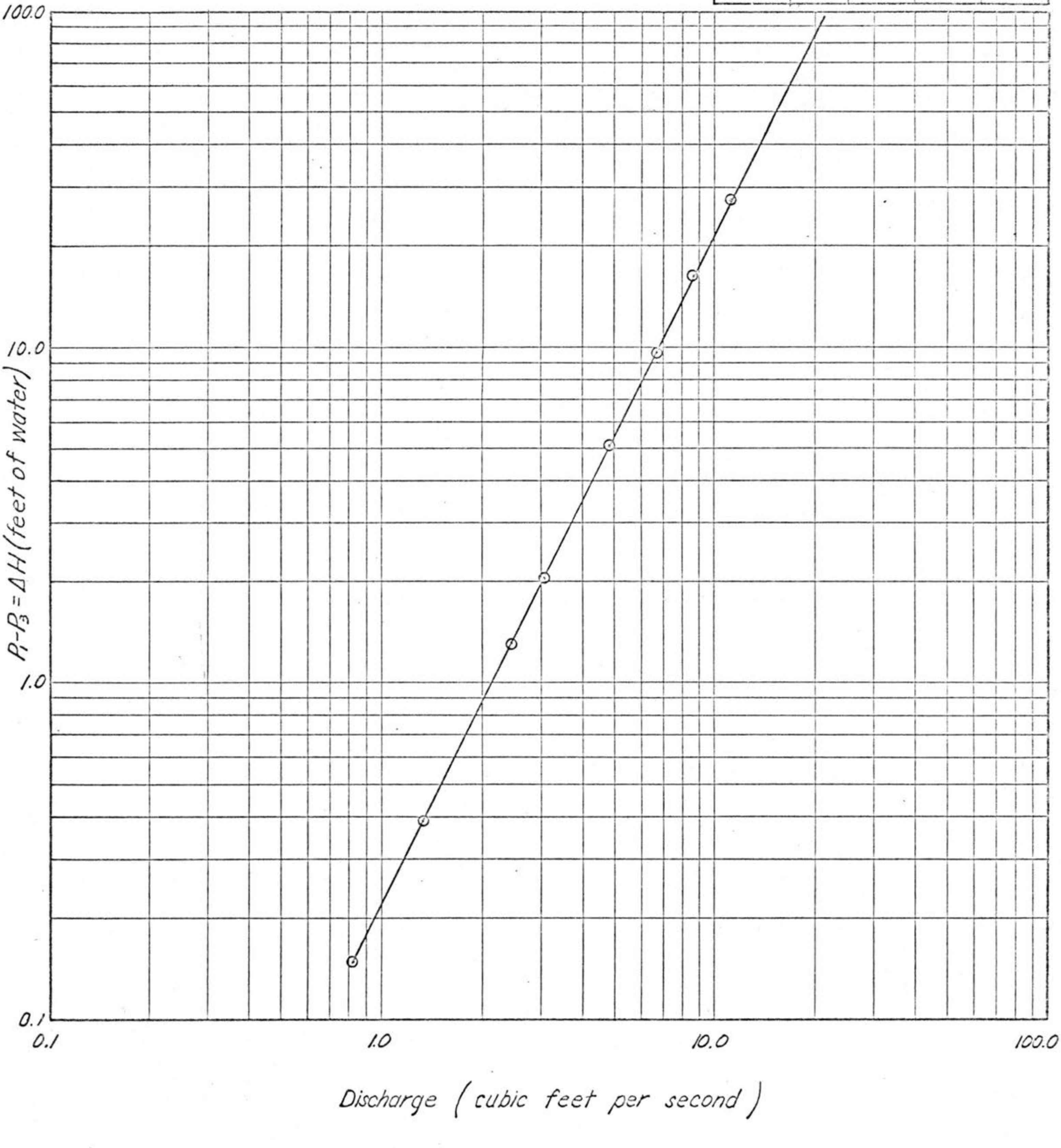
Q vs ΔH Calibration
(In-situ calibration with twenty four-inch downstream expansion)


Potentiometer
Butterfly Valve For Maintaining Back Pressure
Pressure Gauge
Water Supply
7'-5 3/8"
10'-5 3/8"
3 1/2"
4 1/2"
11"
4 1/2"
24"
12"
56'-0"
P3
P1
Discharge Into Volumetric Tank
HYDRO MACHINERY LABORATORY
COLO. STATE UNIV. FOOT HILLS CAMPUS
Head Discharge Calibration
12" Willamette Ball Valve
Santa Clara Water District
Dwg. by R. Young
Date 1-67
Scale 3/4" = 1'-0"
Proj. no. 2146
Dwg. no. 1011

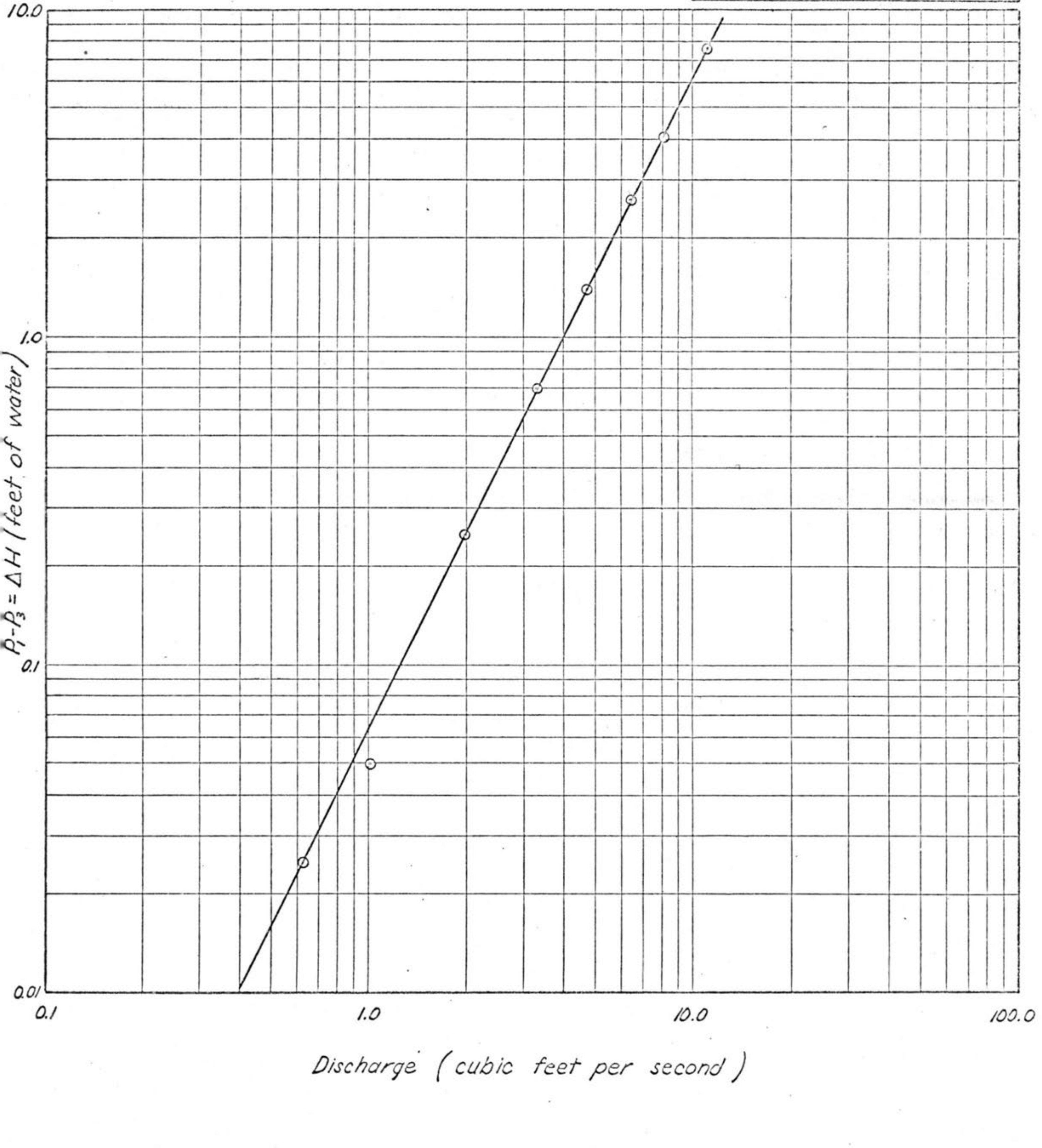

HYDRO MACHINERY LABORATORY
COLO. STATE UNIV. FOOT HILLS CAMPUS
Head Discharge Calibration
12" Willamette Ball Valve
Serial No. 560079
Opening - 20% Rotation
Traced by R. Young
Date 1-67
Scale
Proj. no. 2146
Dwg. no. 1012
100.0
10.0
1.0
0.1
$P_1-P_3=\Delta H$ (feet of water)
0.1
1.0
10.0
100.0
Discharge (cubic feet per second)

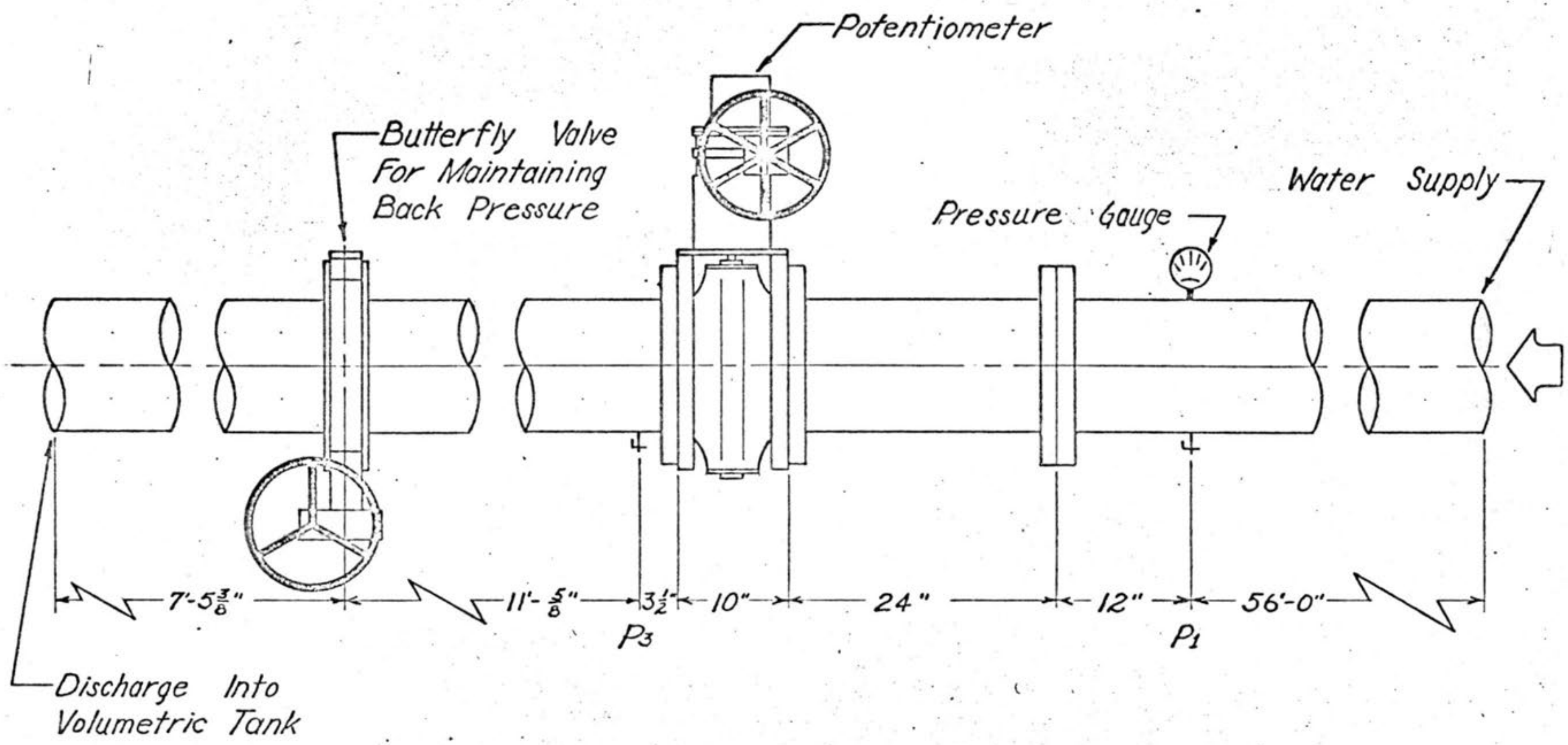

HYDRO MACHINERY LABORATORY
COLO. STATE UNIV. FOOT HILLS CAMPUS
Head Discharge Calibration
12" Willamette Ball Valve
Serial No. 560079
Opening - 35% Rotation
Traced by R. Young
Date 1-67
Scale
Proj. no. 2146
Dwg. no. 1013
100.0
10.0
1.0
0.1
$P_1 - P_3 = \Delta H$ (feet of water)
0.1
1.0
10.0
100.0
Discharge (cubic feet per second)

HYDRO MACHINERY LABORATORY COLO. STATE UNIV. FOOT HILLS CAMPUS				
Head Discharge Calibration 12" Willamette Ball Valve Serial No. 560079 Opening - 50% Rotation				
Traced by R. Young	Date 1-67	Scale	Proj. no. 2146	Dwg. no 1014



HYDRO MACHINERY LABORATORY COLO. STATE UNIV. FOOT HILLS CAMPUS				
Head Discharge Calibration 12" Willamette Ball Valve Serial No. 560079 Opening - 70% Rotation				
Traced by R. Young	Date 1-67	Scale	Proj. no. 2146	Dwg. no. 1015



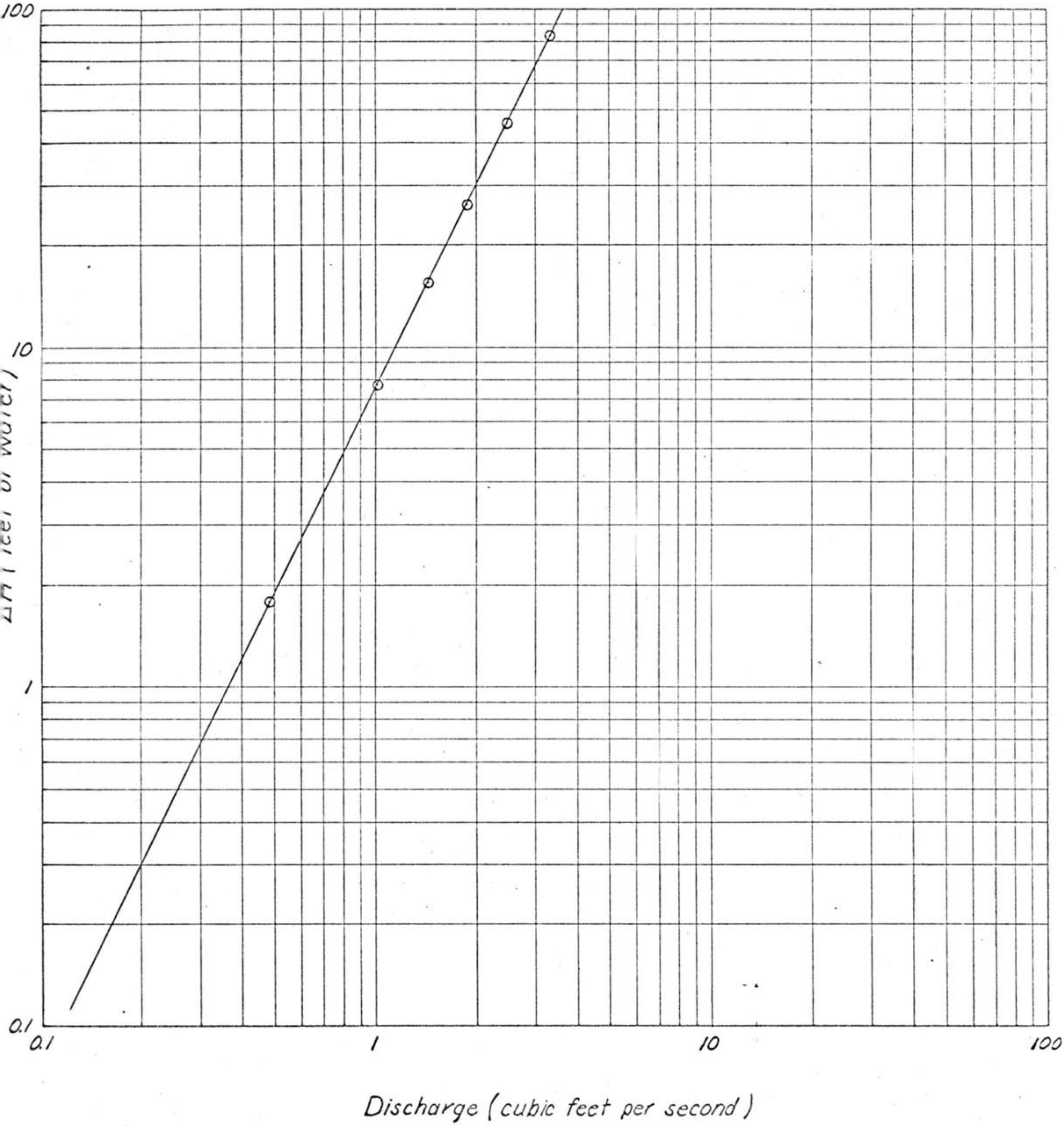


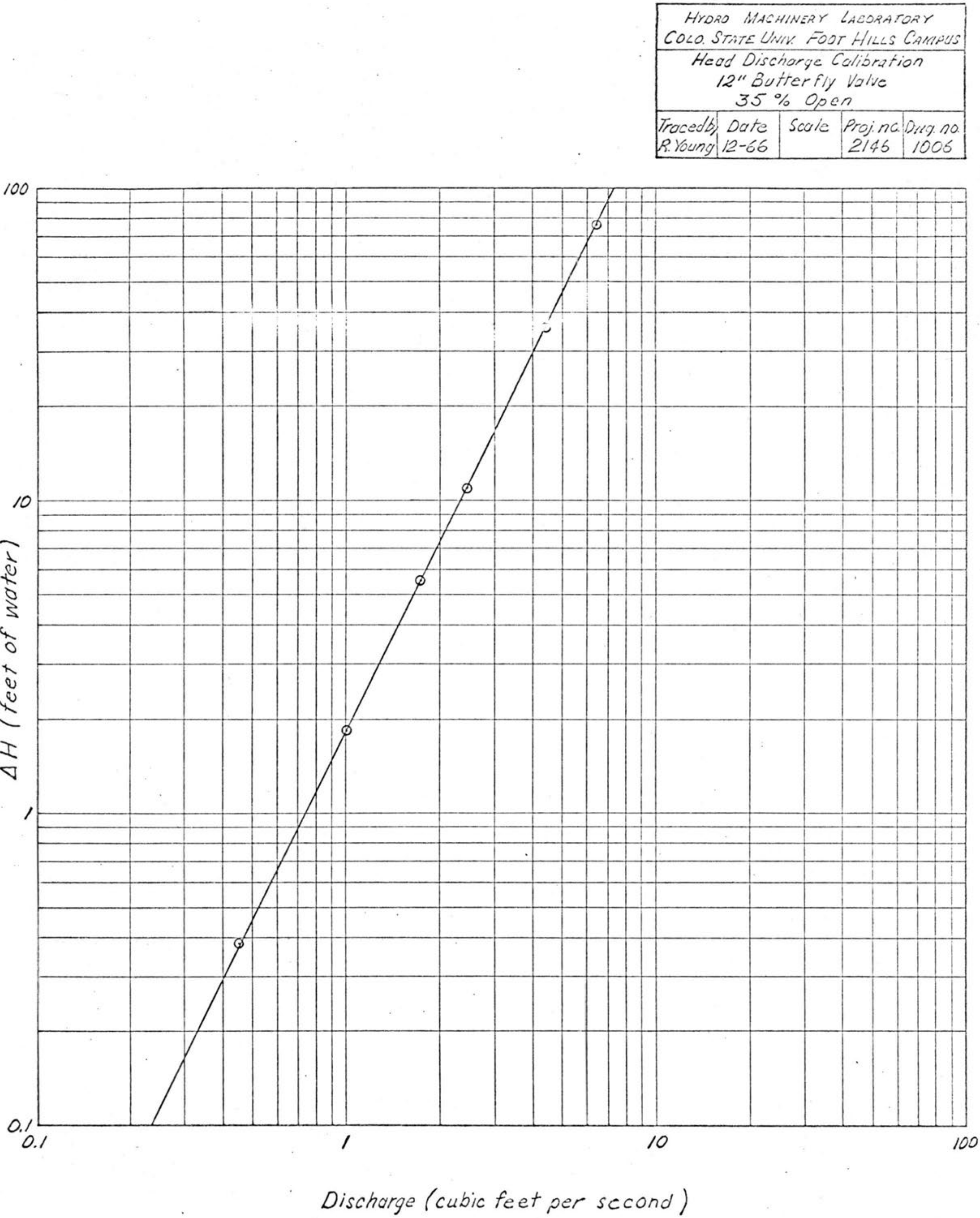
HYDRO MACHINERY LABORATORY
COLO. STATE UNIV. FOOT HILLS CAMPUS

Head Discharge Calibration
12" Butterfly Valve
Santa Clara Water District

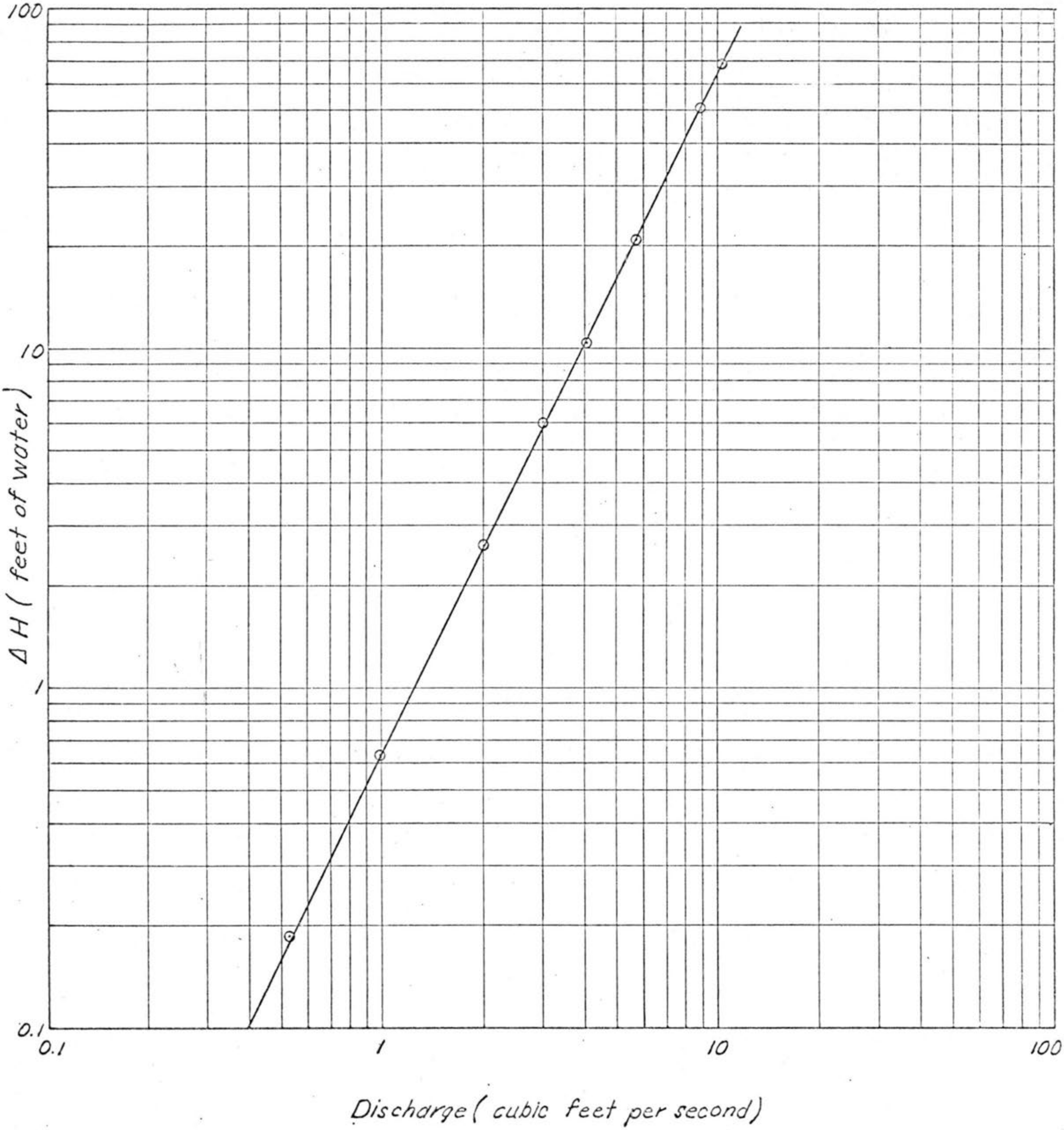
Dwg. by	Date	Scale	Proj. no.	Dwg. no.
R. Young	12-66	1/4" = 1'-0"	2146	1002

HYDRO MACHINERY LABORATORY COLO. STATE UNIV. FOOT HILLS CAMPUS				
Head Discharge Calibration 12" Butterfly Valve 20% Open				
Traced by	Date	Scale	Proj. no.	Dwg. no.
R. Young	12-66		2146	1005

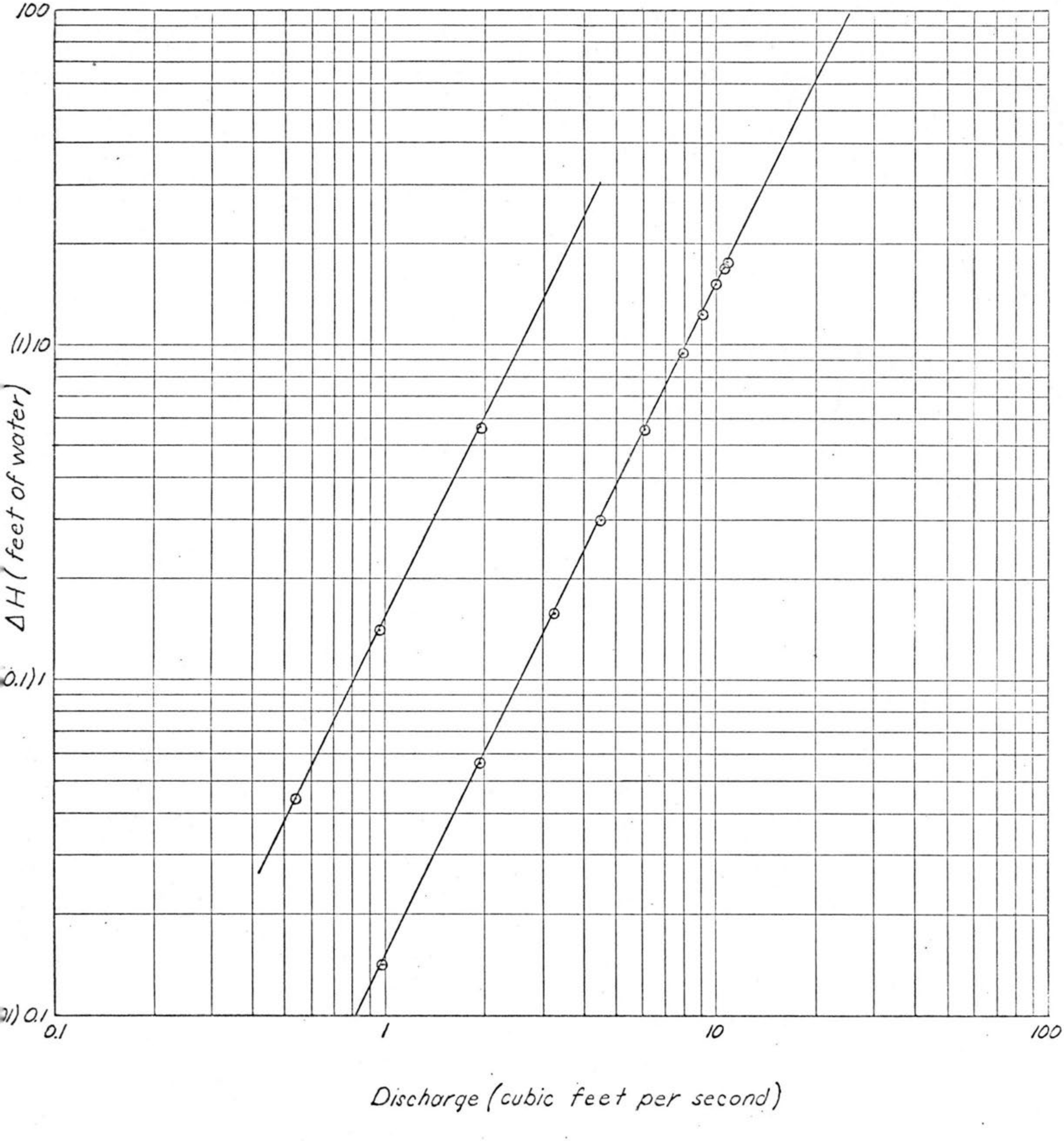


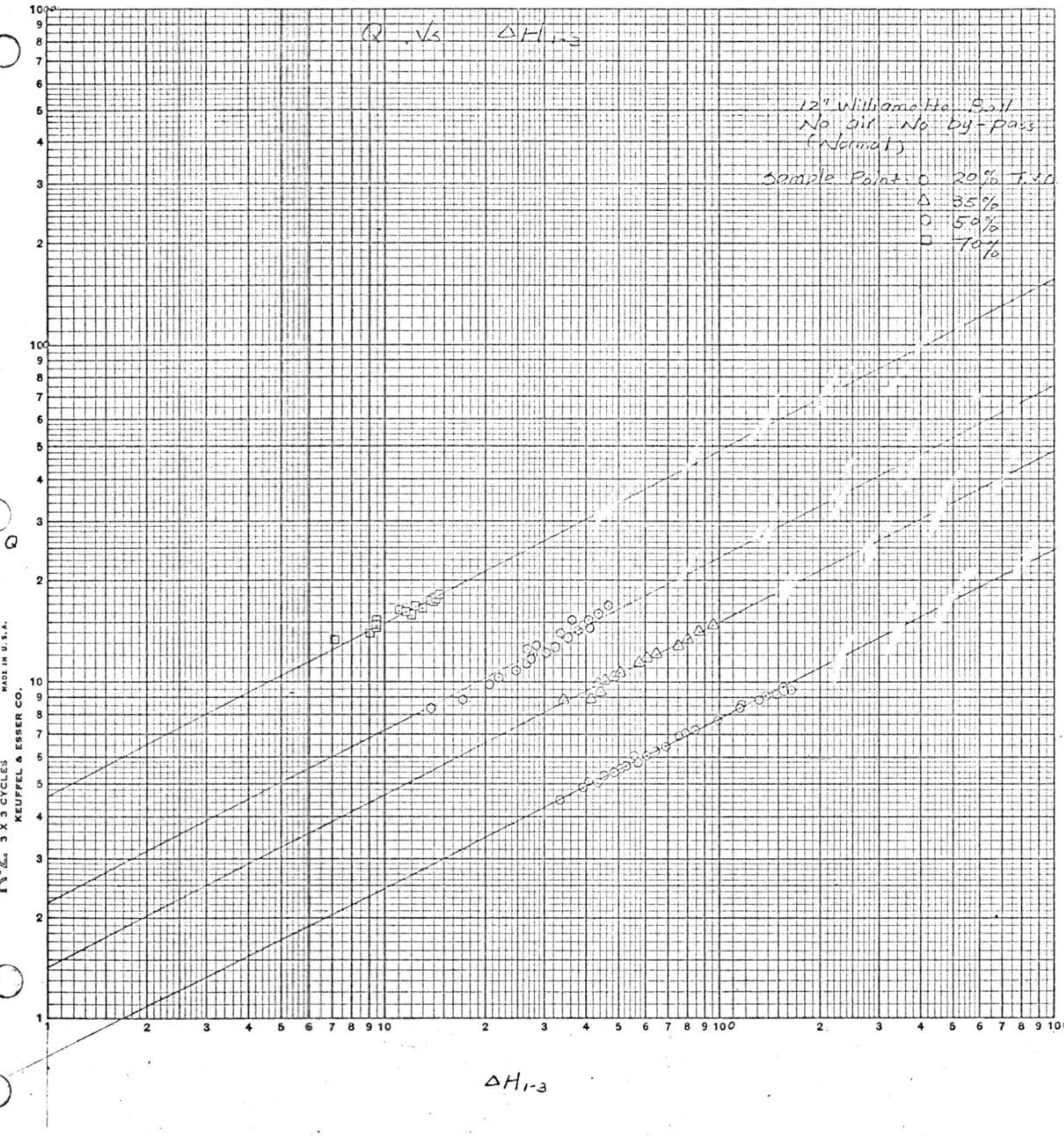

HYDRO MACHINERY LABORATORY
COLO. STATE UNIV. FOOT HILLS CAMPUS
Head Discharge Calibration
12" Butterfly Valve
35 % Open
Traced by R. Young
Date 12-66
Scale
Proj. no. 2146
Dwg. no. 1006
100
10
1
0.1
ΔH (feet of water)
0.1
1
10
100
Discharge (cubic feet per second)

HYDRO MACHINERY LABORATORY COLO. STATE UNIV. FOOT HILLS CAMPUS				
Head Discharge Calibration 12" Butterfly Valve 50% Open				
Traced by R. Young	Date 12-66	Scale	Proj. no. 2146	Dwg. no 1007

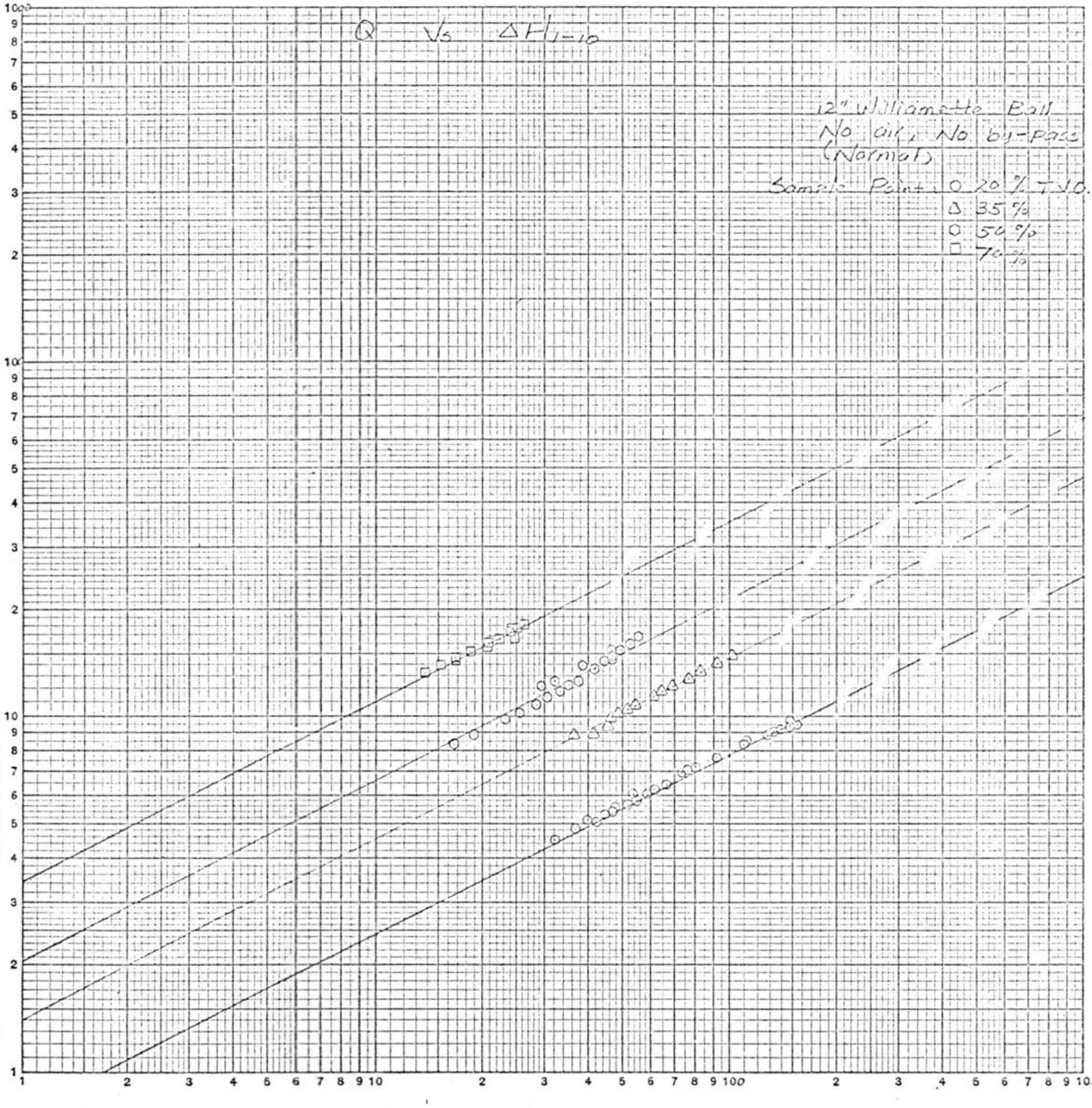


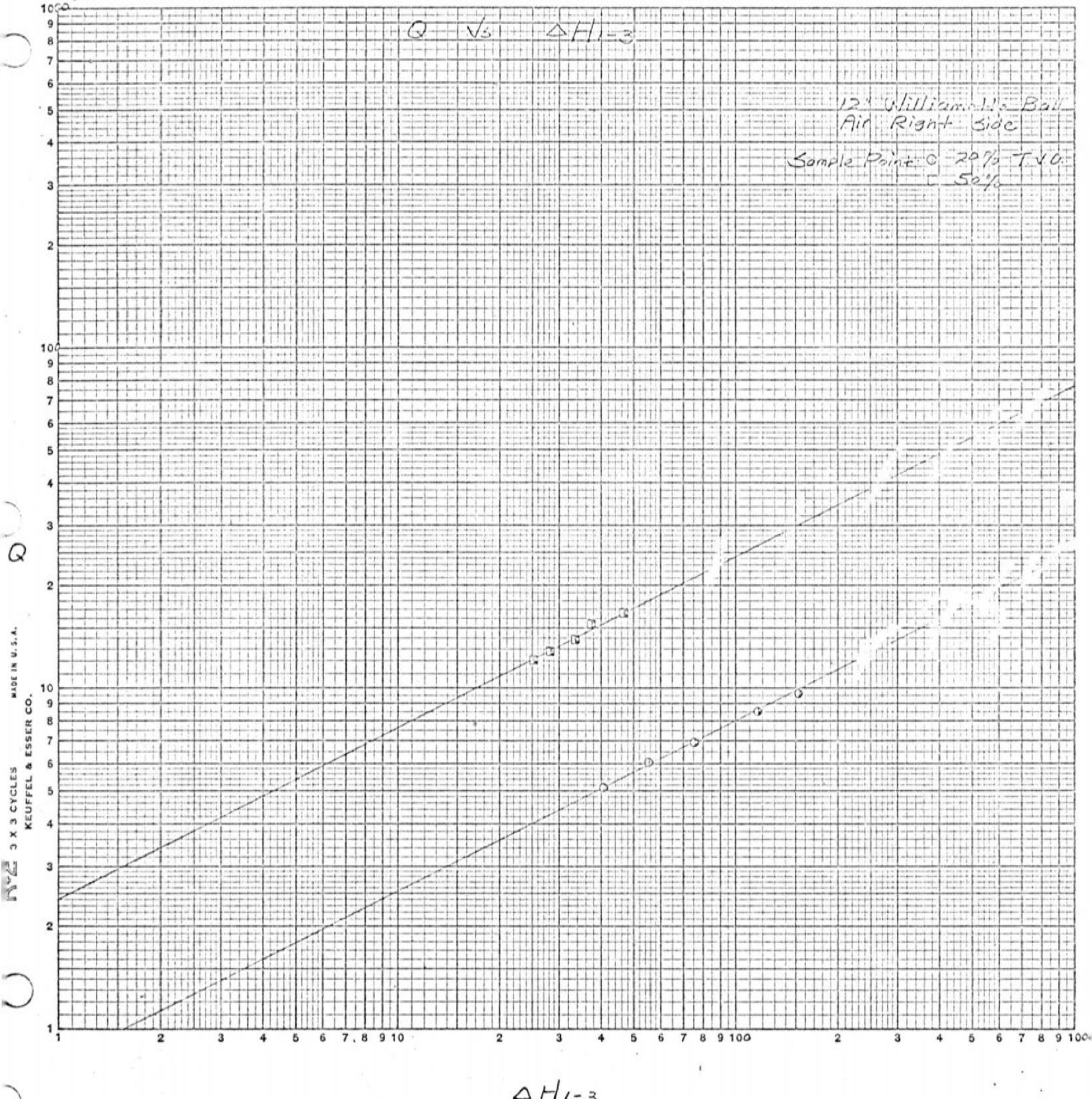
Hydro Machinery Laboratory Colo. State Univ. Foot Hills Campus				
Head Discharge Calibration 12" Butterfly Valve 70 % Open				
Traced by R. Young	Date 12-66	Scale	Proj. no. 2146	Dwg. no. 1008

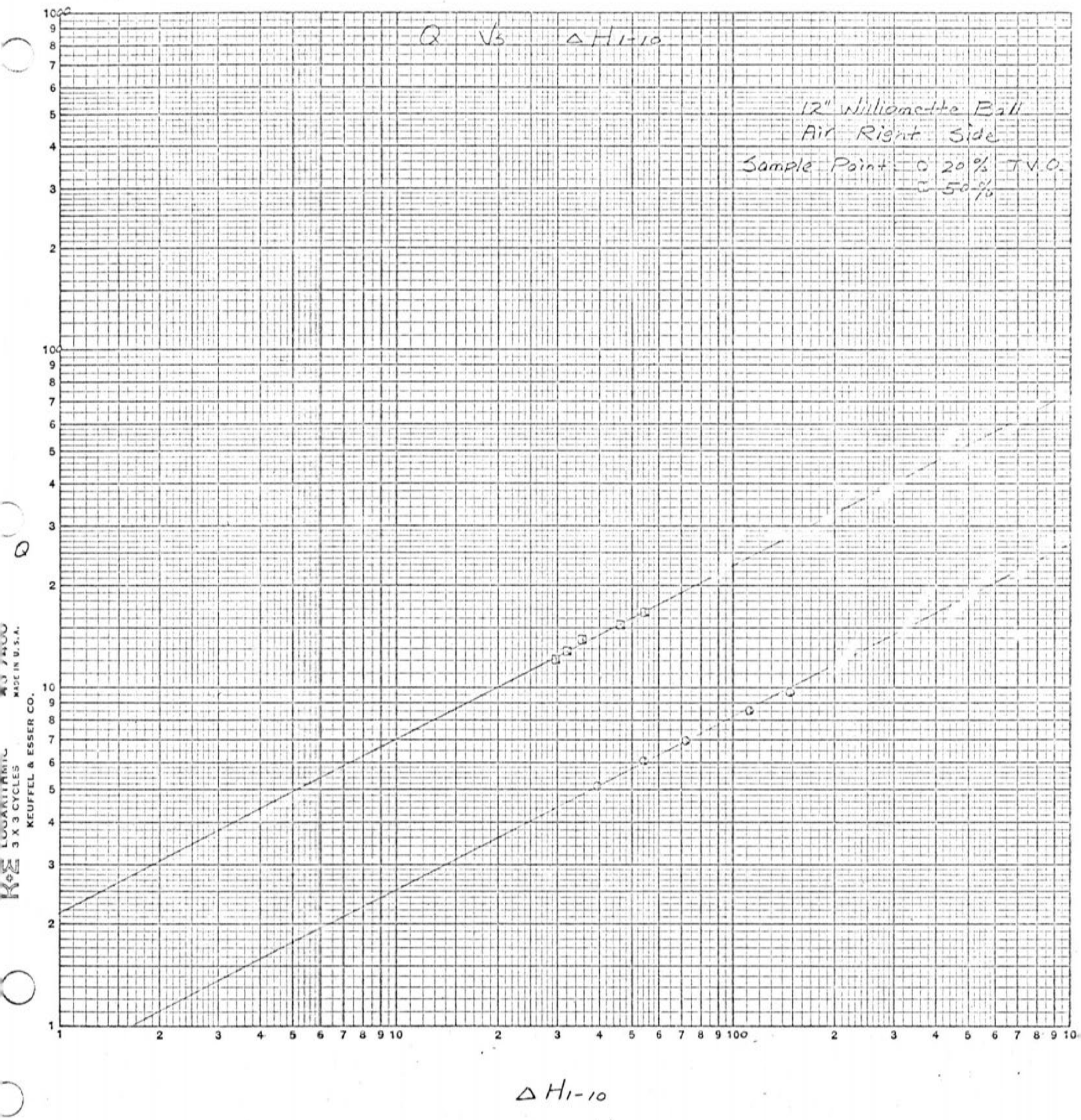




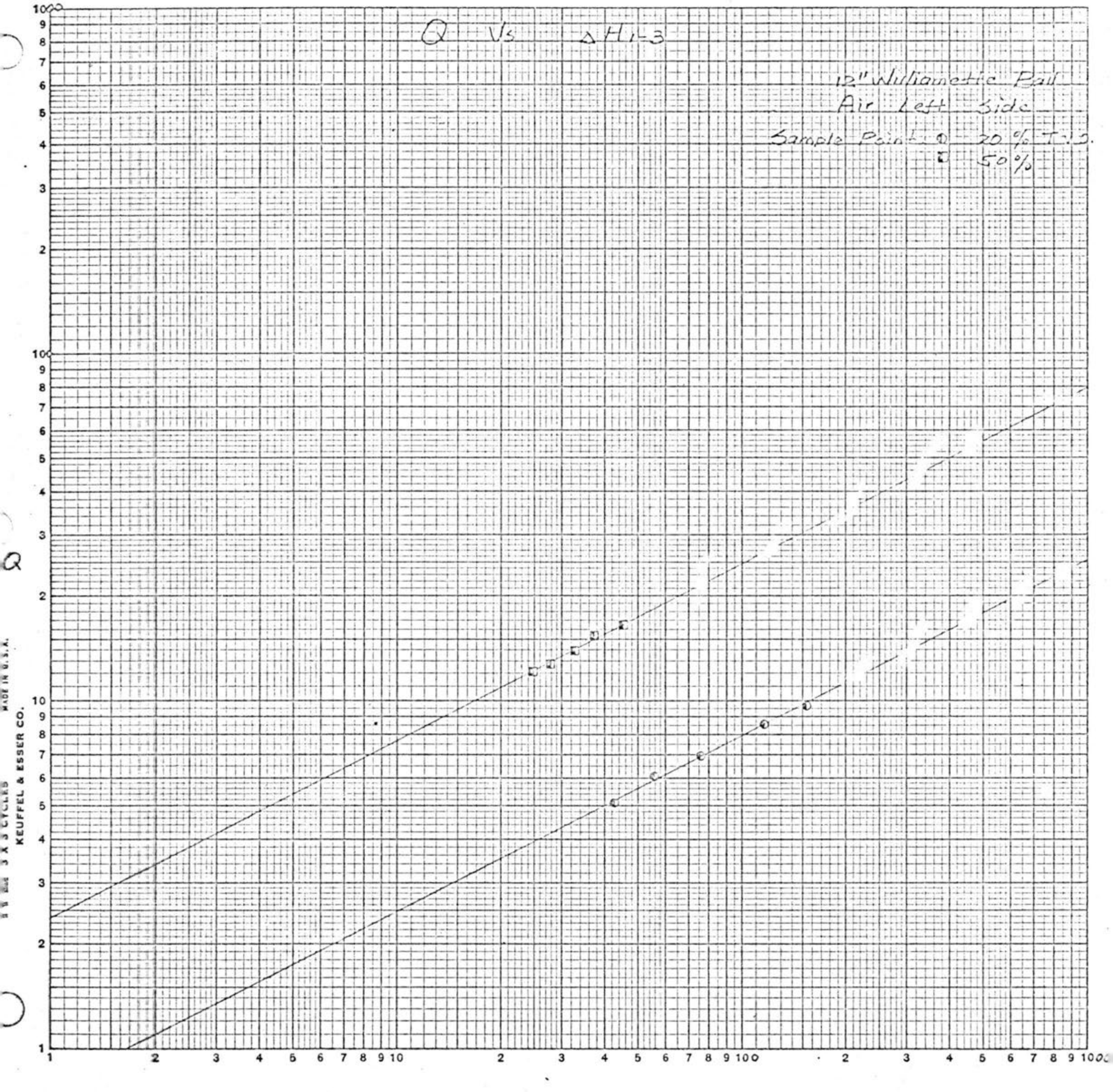
Q vs ΔH1-3
12" Willamette Soil
No air No by-pass
(Normal)
Sample Point: ○ 20% T.S.C.
△ 35%
○ 50%
□ 70%
Q
ΔH1-3
3 X 3 CYCLES
KEUFFEL & ESSER CO.
MADE IN U.S.A.

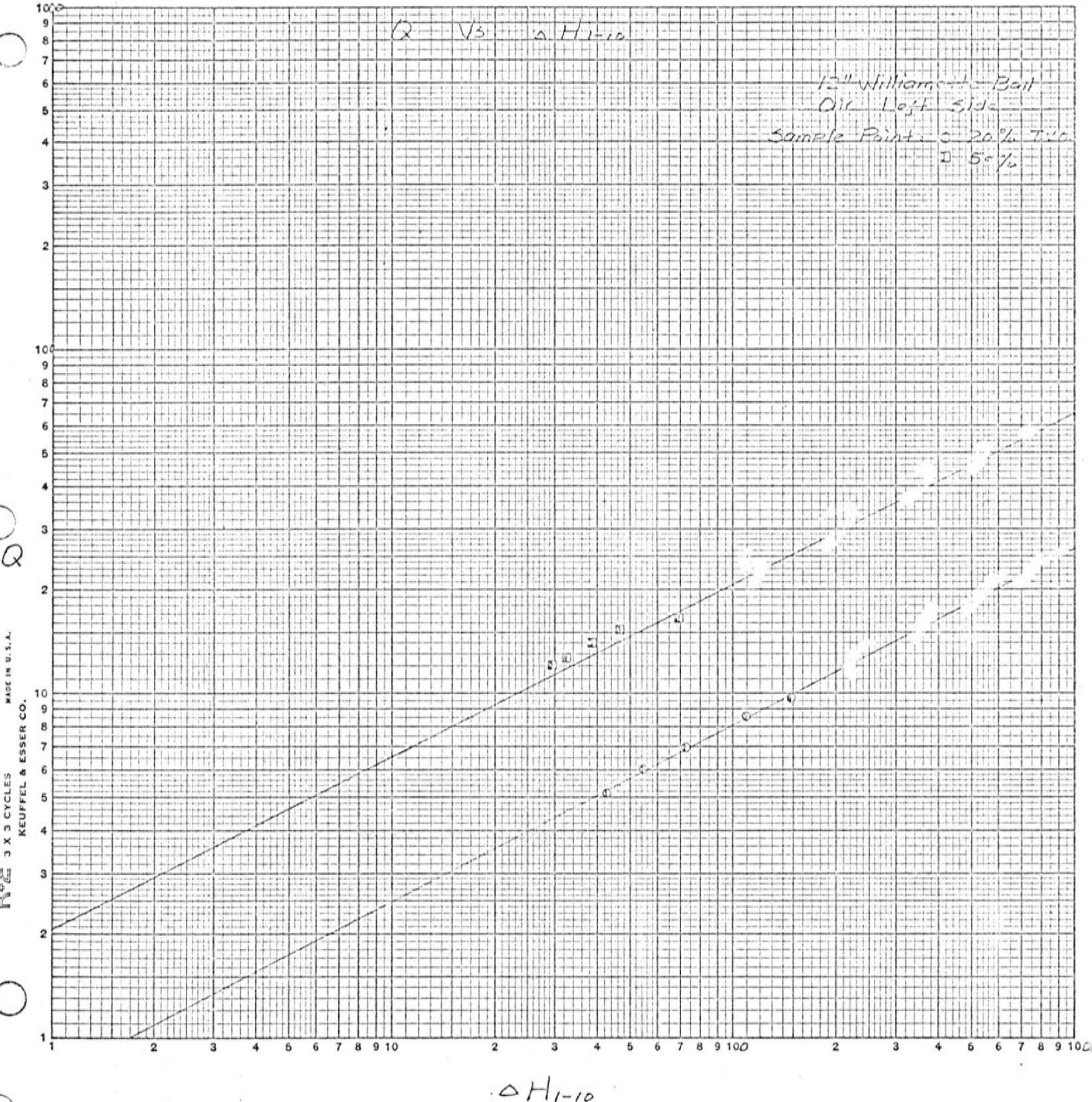

Q Vs ΔH1-10
12" Williamette Ball
No air, No by-pass
(Normal)
Sample Point: ○ 20% T.V.O.
△ 35%
○ 50%
□ 70%
Q
ΔH1-10
3 X 3 CYCLES
KEUFFEL & ESSER CO.
MADE IN U.S.A.

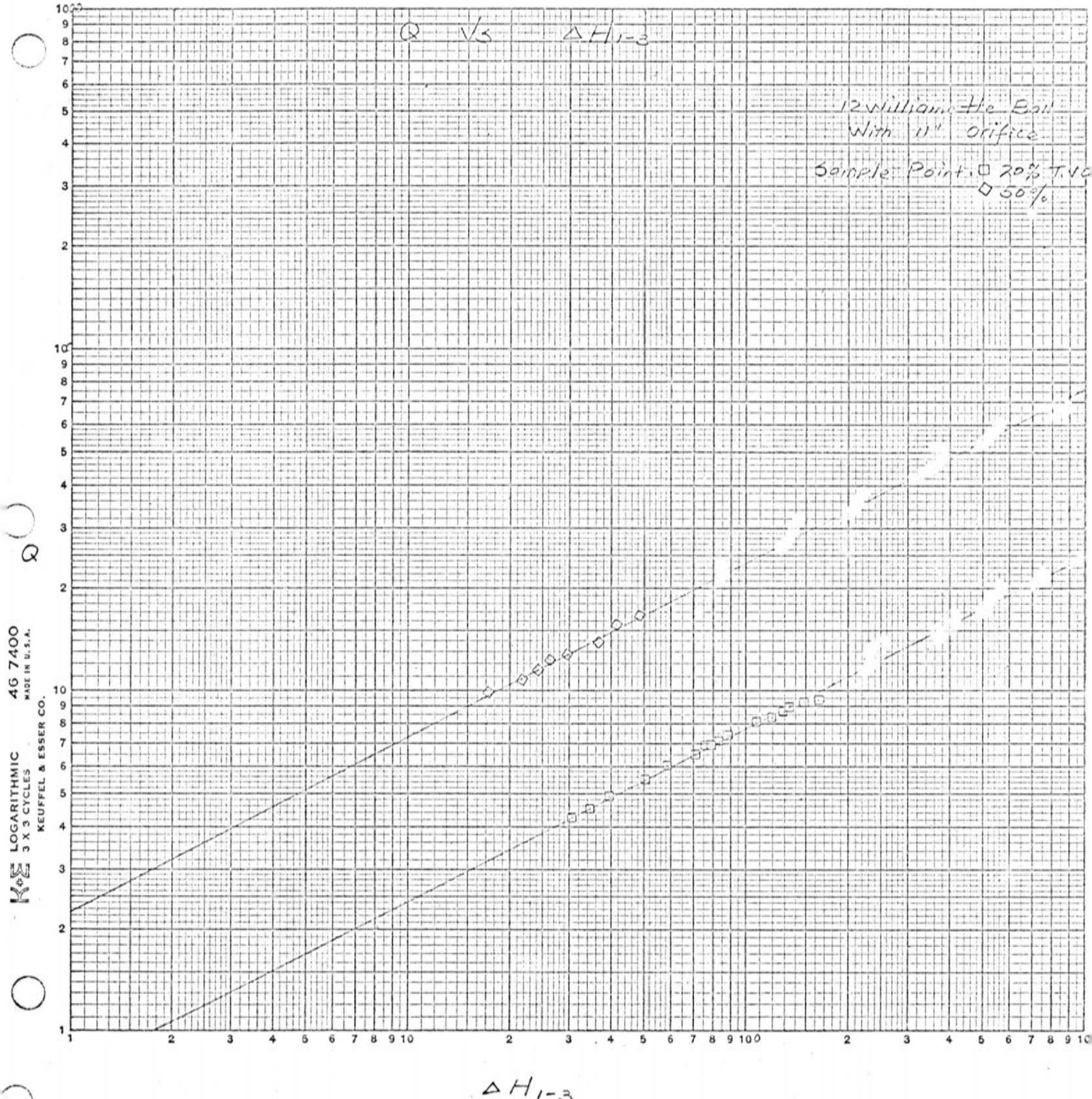

Q Vs ΔH1-3
12" Willamette Ball
Air Right Side
Sample Point: ○ 20% T.V.O.
□ 50%
Q
ΔH1-3
1000
100
10
1
2
3
4
5
6
7
8
9
10
100
1000
3 X 3 CYCLES
KEUFFEL & ESSER CO.
MADE IN U.S.A.

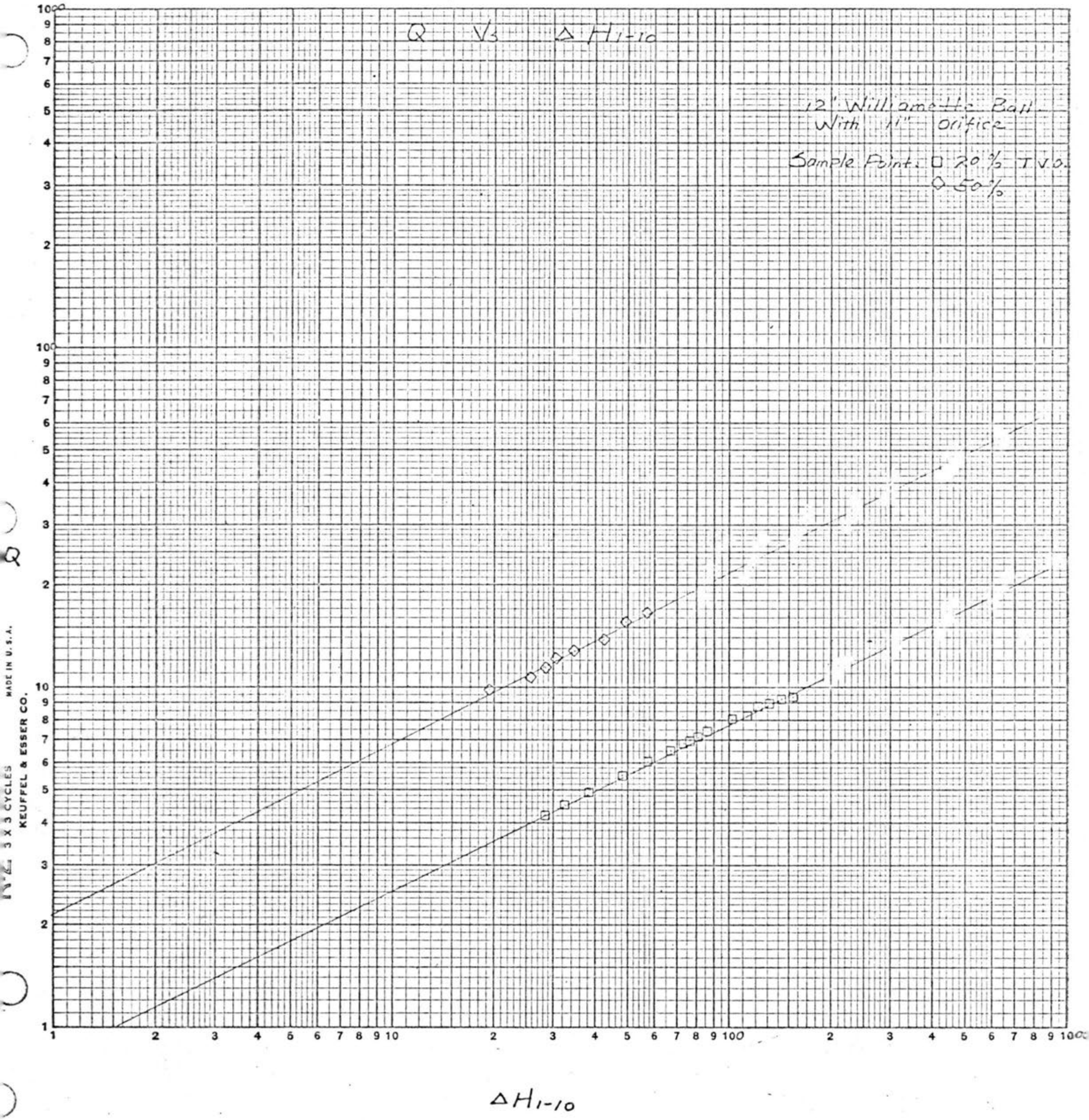


Q Vs ΔH1-10
12" Williamette Ball
Air Right Side
Sample Point: ○ 20% T.V.O.
□ 50%
Q
ΔH1-10
K&E LOGARITHMIC 3 X 3 CYCLES
KEUFFEL & ESSER CO.
MADE IN U.S.A.

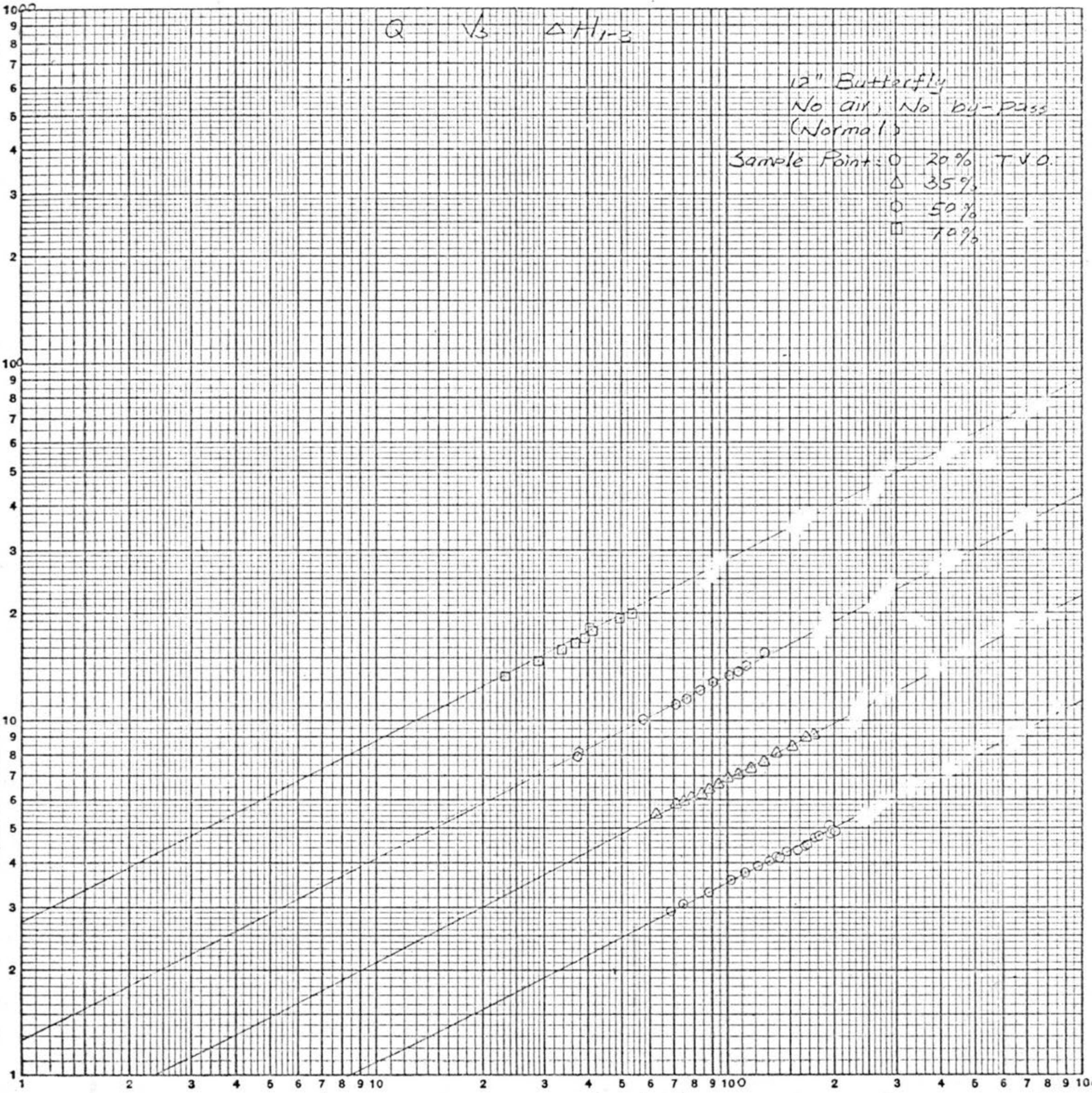

Q Vs ΔH1-3
12" Williametic Rail
Air Left Side
Sample Point ⊙ 20 % T.D.
⊡ 50%
Q
ΔH1-3
KEUFFEL & ESSER CO.
MADE IN U.S.A.

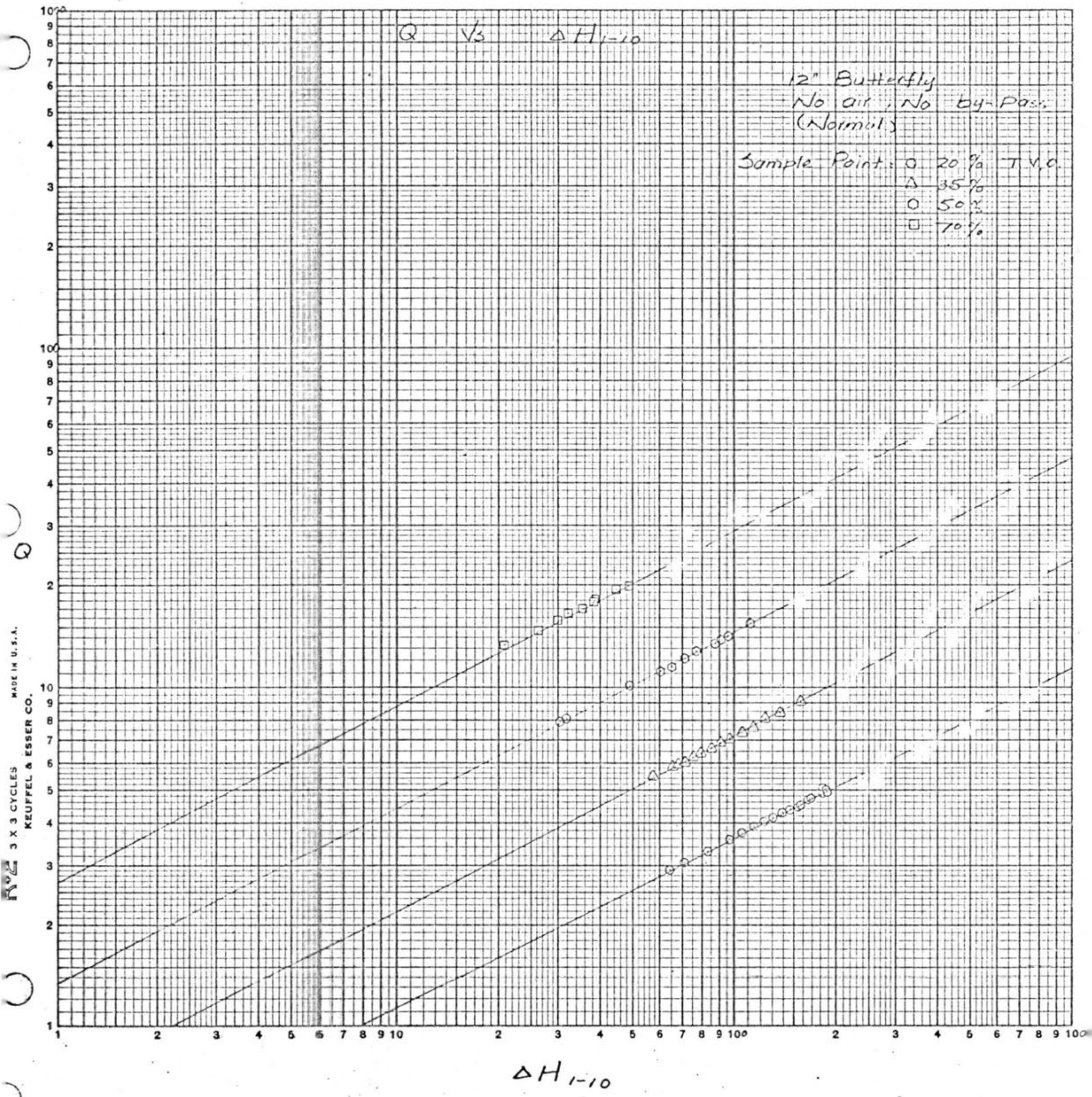

Q Vs ΔH1-10
12" Williamette Bail
Air Left Side
Sample Point: ○ 20% T.V.C.
□ 50%
Q
ΔH1-10
K+E LOGARITHMIC 46 7400
3 X 3 CYCLES MADE IN U.S.A.
KEUFFEL & ESSER CO.


Q Vs ΔH1-3
12 Willamette Ball
With 11" Orifice
Sample Point · □ 20% T.V.C
◇ 50%
Q
ΔH1-3
K&E LOGARITHMIC 3 X 3 CYCLES KEUFFEL & ESSER CO.
46 7400 MADE IN U.S.A.

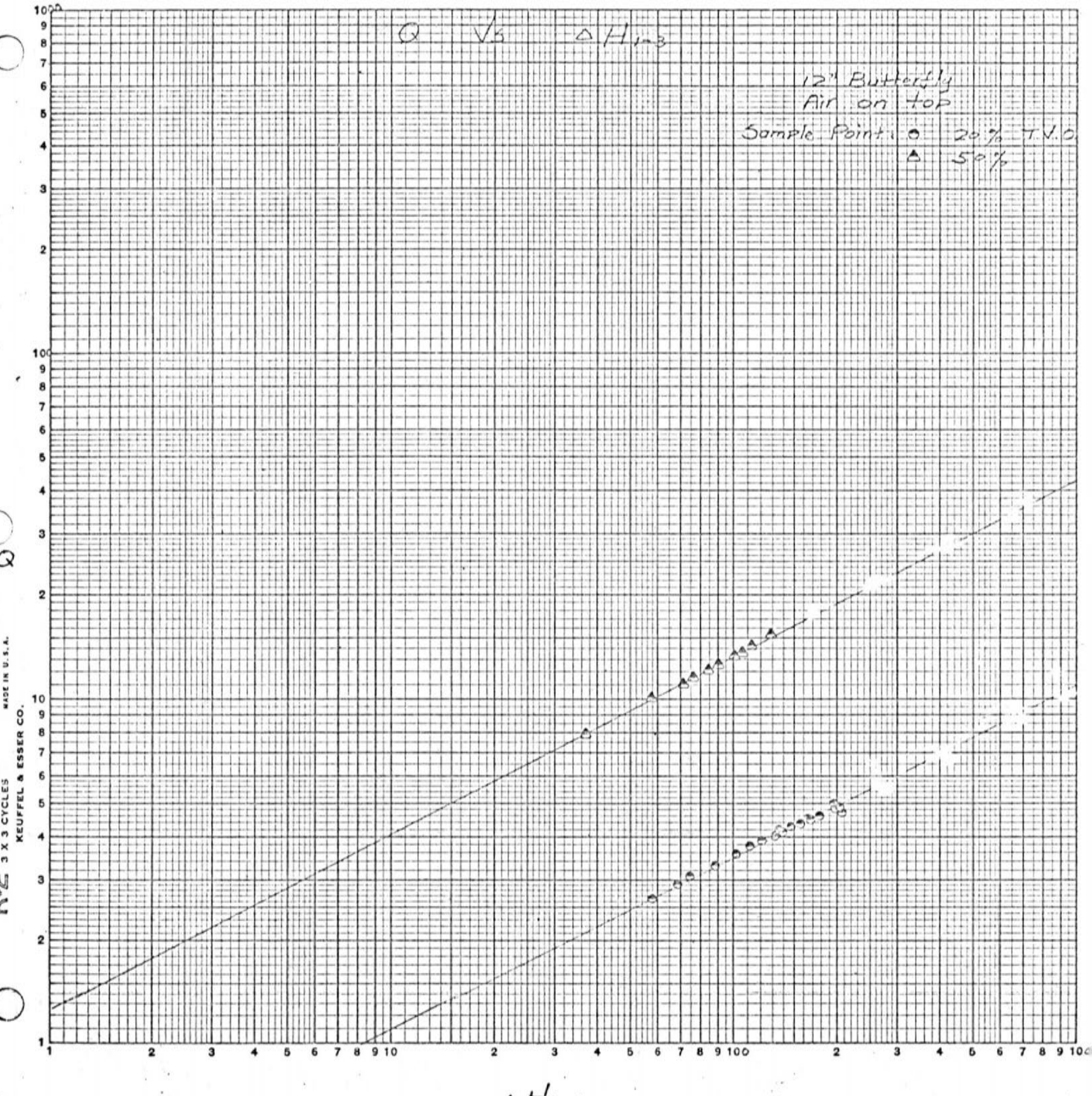


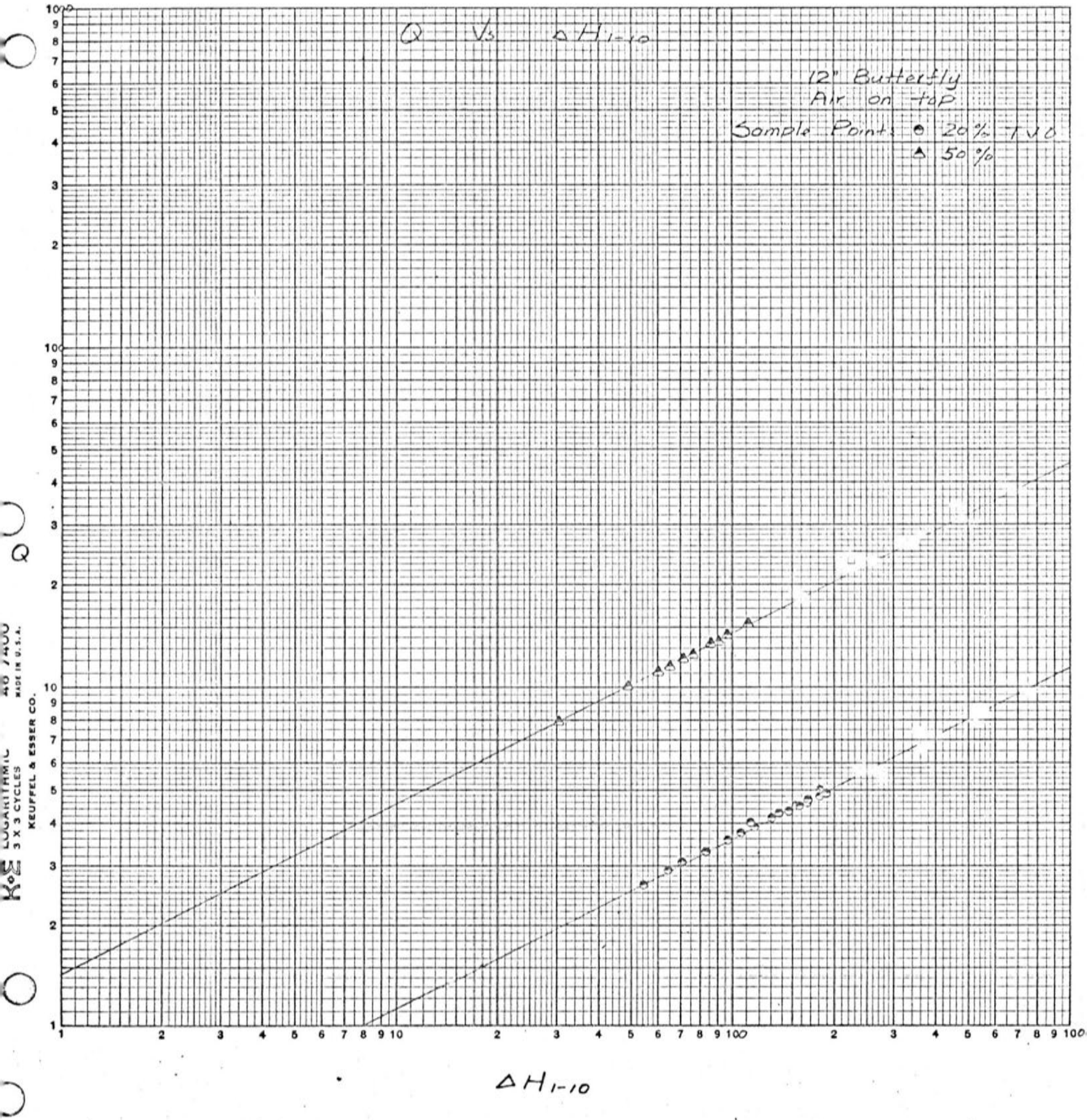
Q Vs ΔH1-10
12" Willamette Ball
With 11" Orifice
Sample Point: □ 20% T.V.O.
◇ 50%
Q
ΔH1-10
3 X 3 CYCLES
KEUFFEL & ESSER CO.
MADE IN U.S.A.


Q Vs ΔH1-3
12" Butterfly
No air, No by-pass
(Normal)
Sample Point: ○ 20% T.V.O.
△ 35%
⌀ 50%
□ 70%
Q
ΔH1-3
K+E 3 X 3 CYCLES
KEUFFEL & ESSER CO.
MADE IN U.S.A.

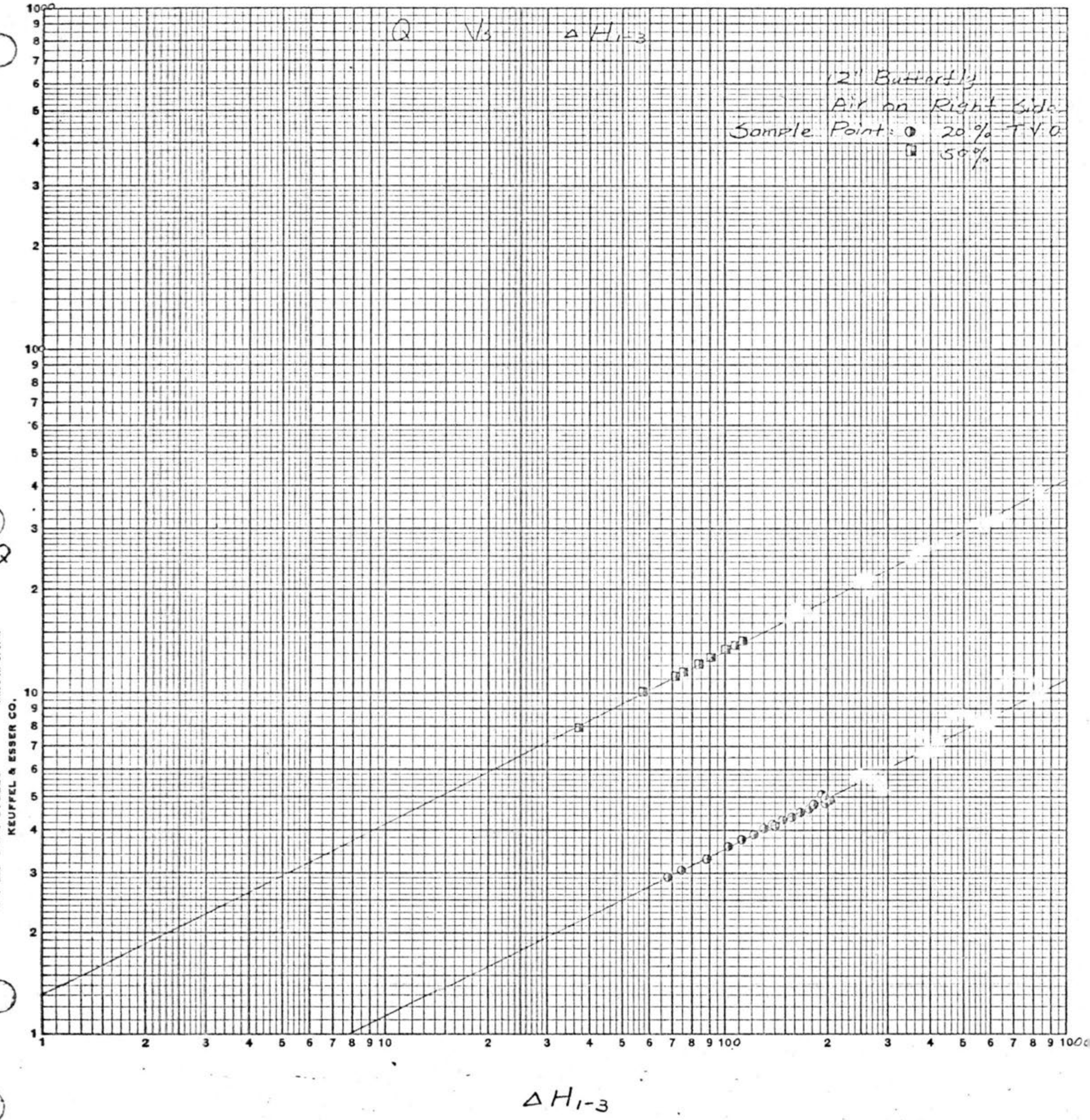


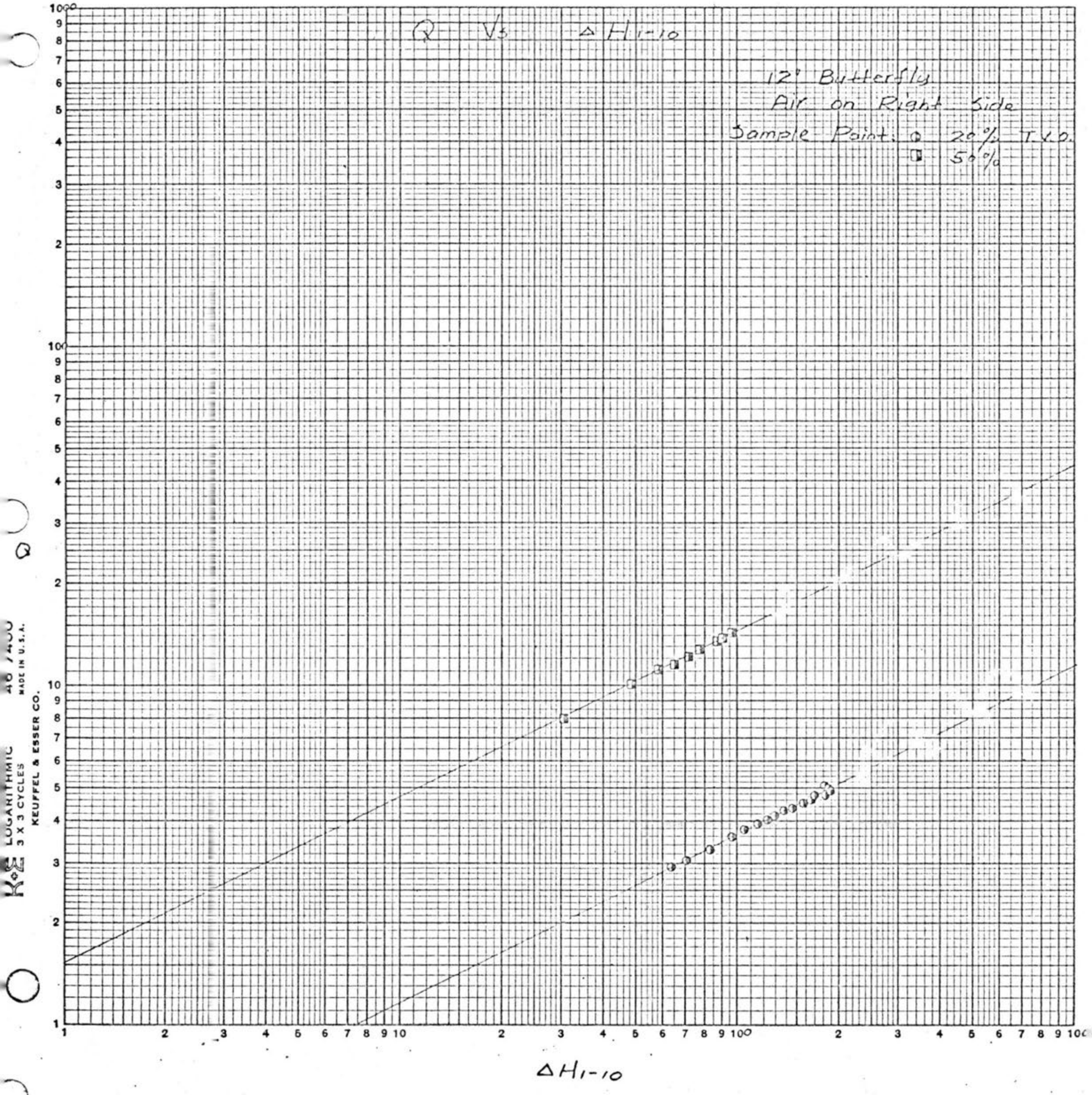
Q Vs ΔH1-10
12" Butterfly
No air, No by-Pass
(Normal)
Sample Point: ○ 20% T.V.O.
△ 35%
⬡ 50%
□ 70%
Q
ΔH1-10
3 X 3 CYCLES
KEUFFEL & ESSER CO.
MADE IN U.S.A.

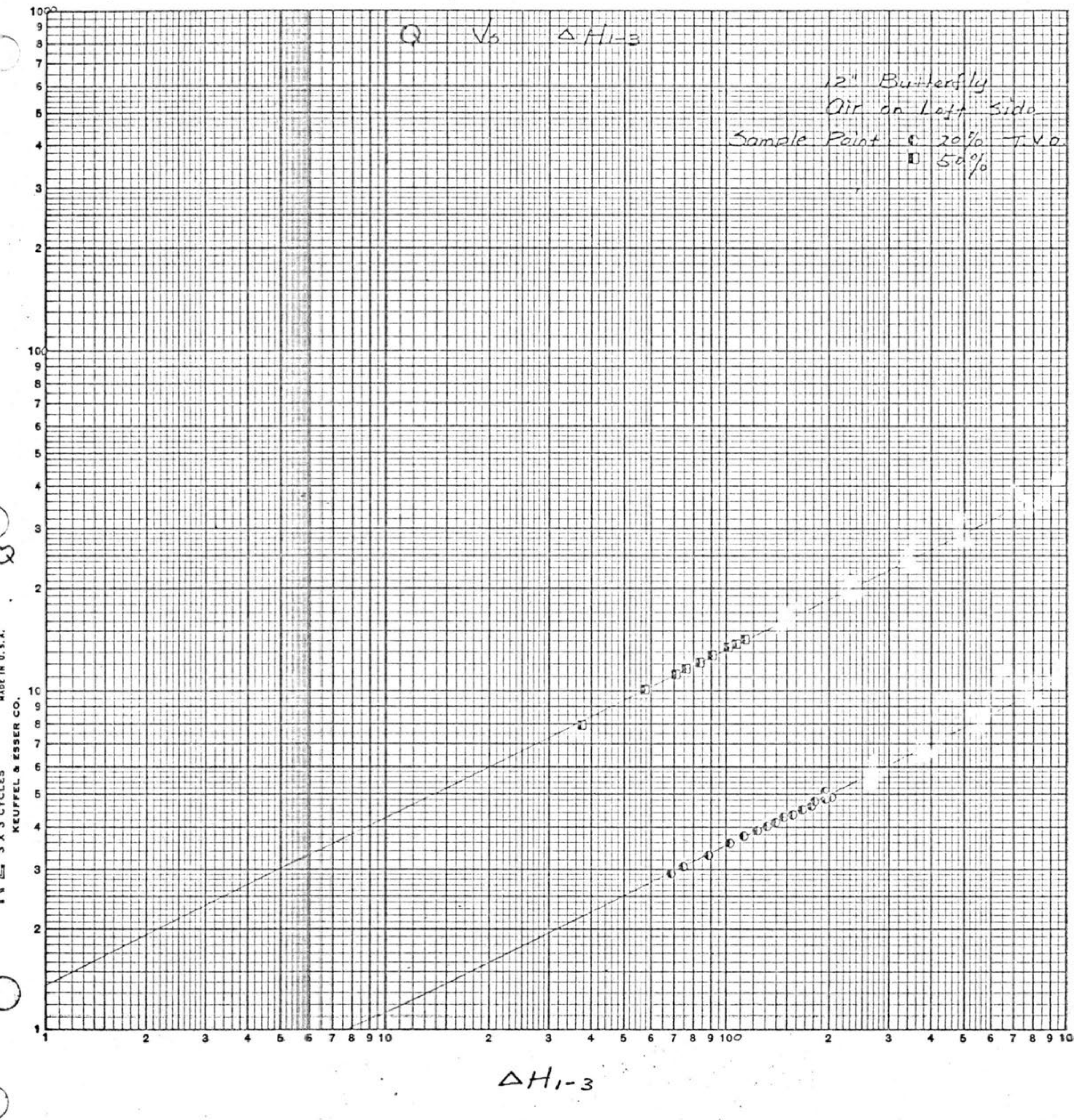

Q Vs ΔH1-3
12" Butterfly
Air on top
Sample Point: o 20% T.V.O.
Δ 50%
Q
ΔH1-3
K&E LOGARITHMIC 3 X 3 CYCLES
KEUFFEL & ESSER CO.
46 7400
MADE IN U.S.A.

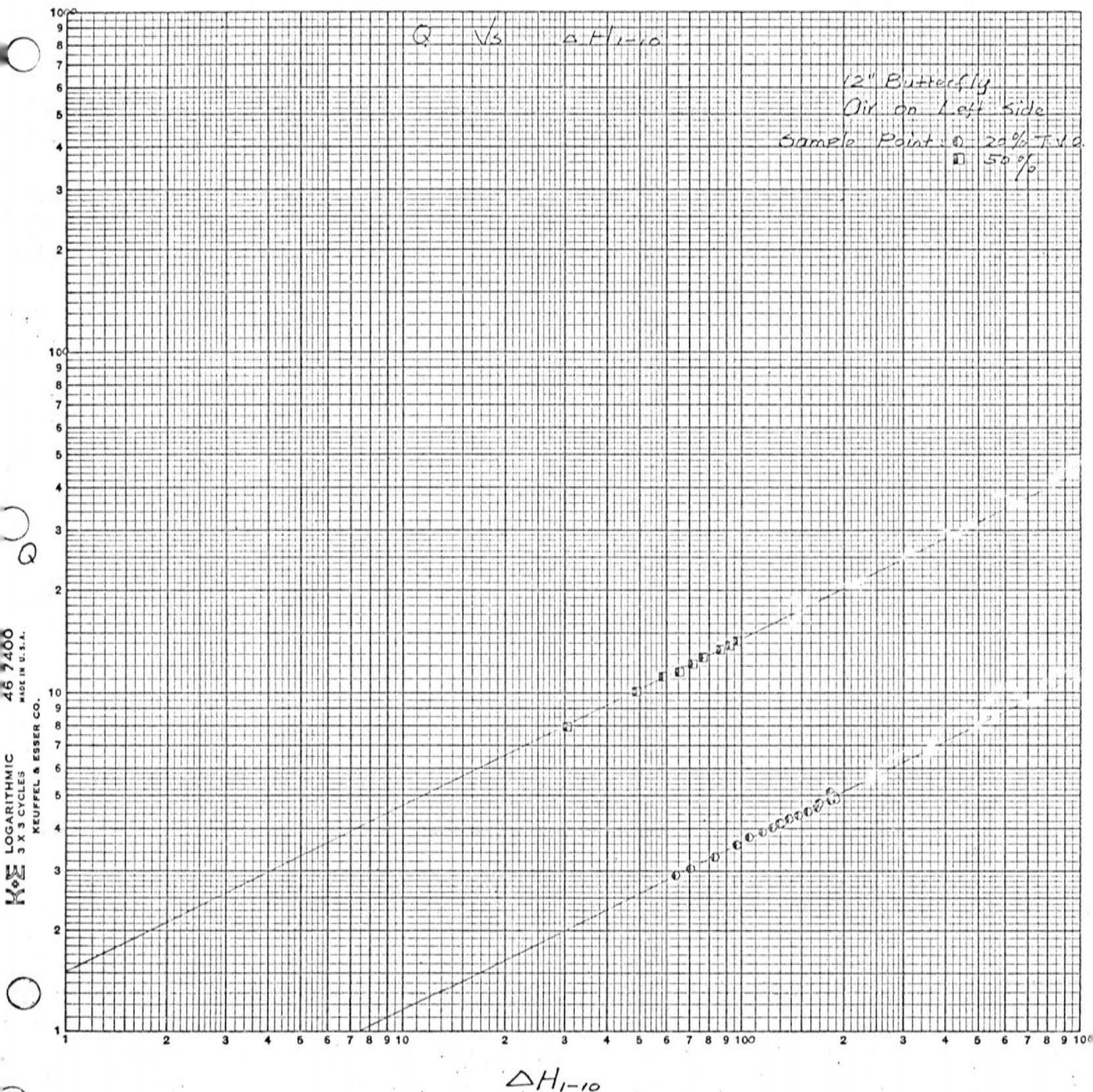


Q Vs ΔH1-10
12" Butterfly
Air on top
Sample Points ● 20% TVO
▲ 50%
Q
ΔH1-10
LOGARITHMIC 46 7400
3 X 3 CYCLES
KEUFFEL & ESSER CO.
MADE IN U.S.A.

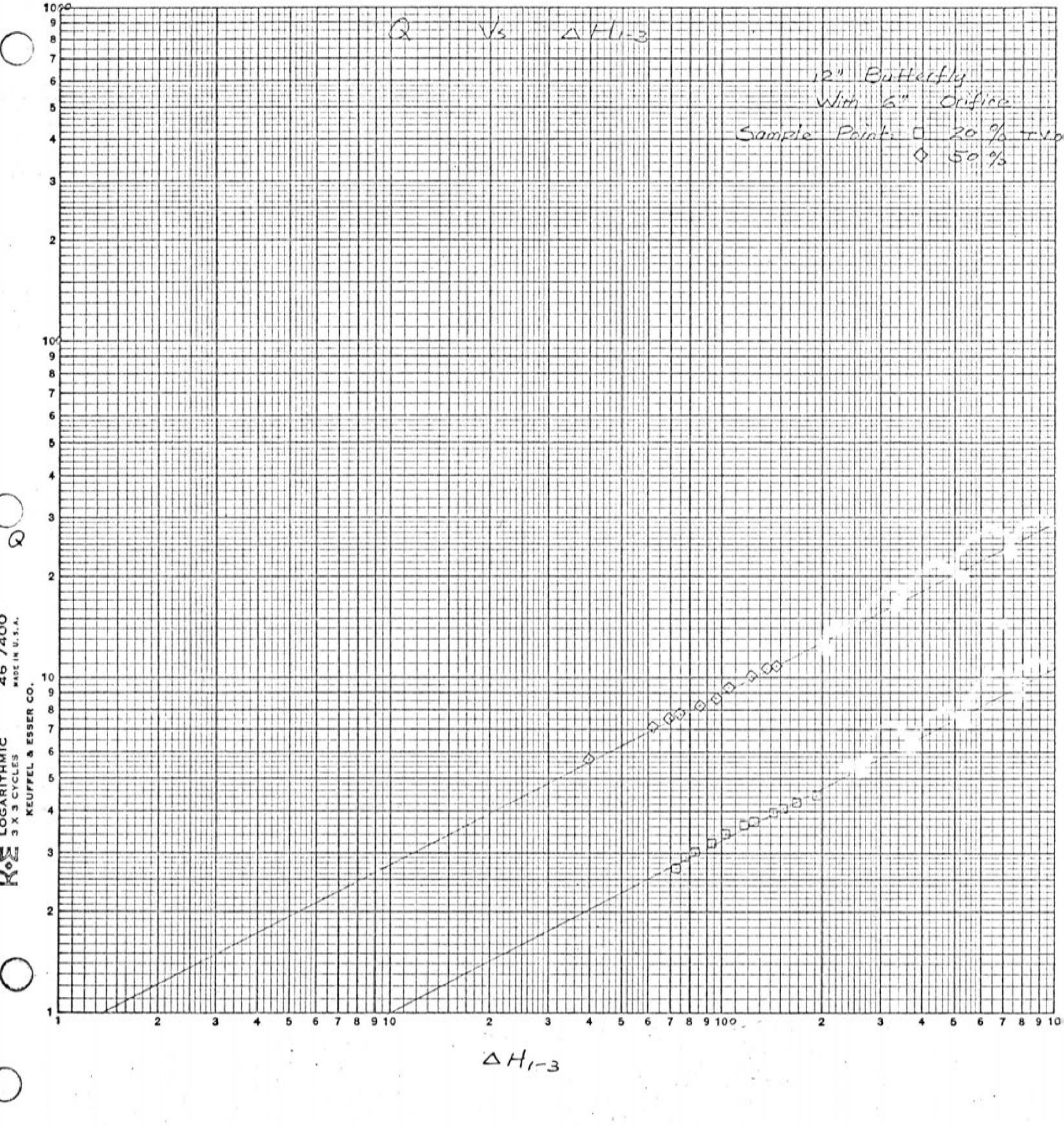

Q vs ΔH1-3
12" Butterfly
Air on Right Side
Sample Point: ● 20% TVO
■ 50%
Q
ΔH1-3
KEUFFEL & ESSER CO.
3 X 3 CYCLES
MADE IN U.S.A.

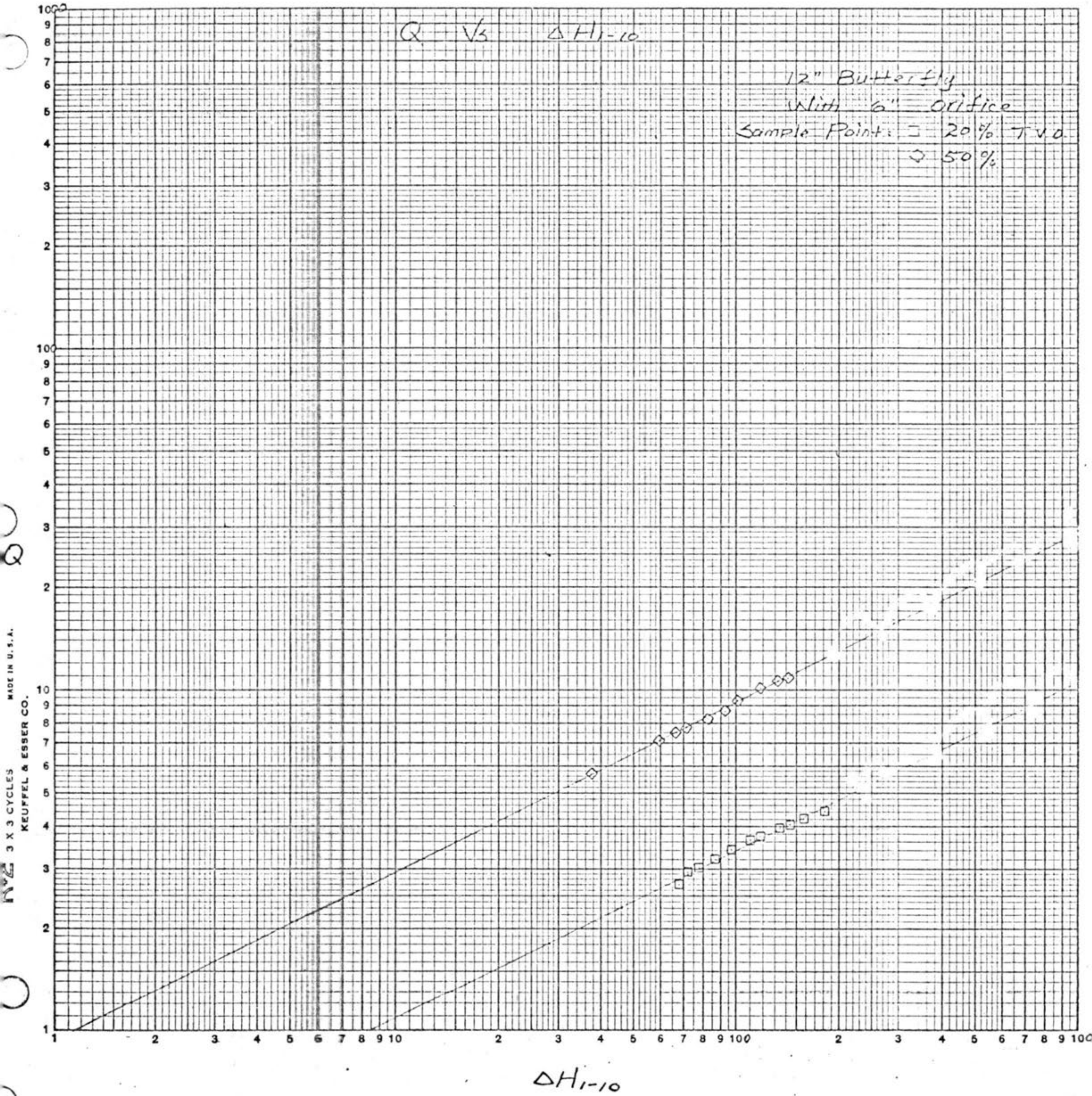

Q Vs ΔH1-10
12" Butterfly
Air on Right Side
Sample Point: 20% T.V.O.
50%
Q
ΔH1-10
K&E LOGARITHMIC
3 X 3 CYCLES
KEUFFEL & ESSER CO.
MADE IN U.S.A.


Q Vs ΔH1-3
12" Butterfly
Air on Left Side
Sample Point ◐ 20% T.V.O.
◫ 50%
ΔH1-3
Q
3 X 3 CYCLES
KEUFFEL & ESSER CO.
MADE IN U.S.A.

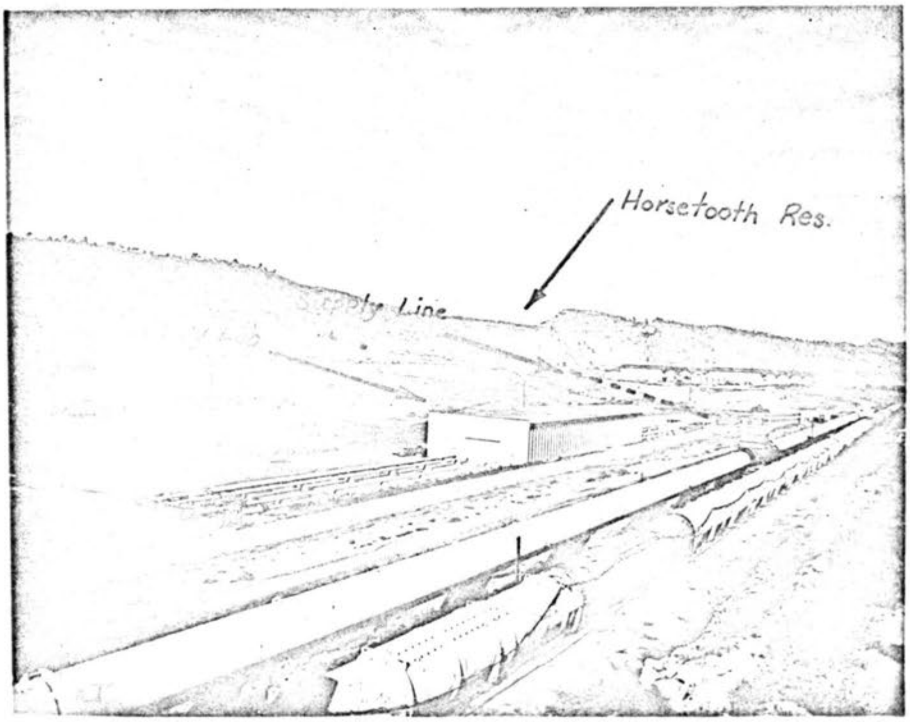


Q Vs ΔH1-10
12" Butterfly
Oil on Left Side
Sample Point: ◐ 20% T.V.O.
◧ 50%
Q
ΔH1-10
KE LOGARITHMIC 3 X 3 CYCLES KEUFFEL & ESSER CO.
46 7400 MADE IN U.S.A.

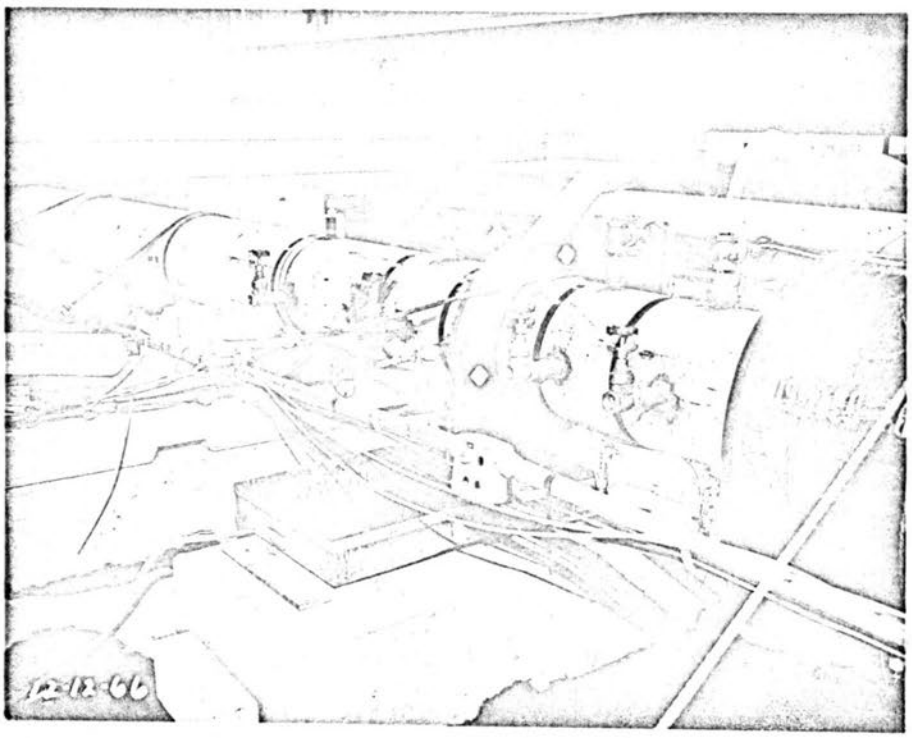

Q Vs ΔH1-3
12" Butterfly
With 6" Orifice
Sample Point: □ 20 %
◇ 50 %
Q
ΔH1-3
LOGARITHMIC 46 7400
3 X 3 CYCLES
KEUFFEL & ESSER CO.


Q Vs ΔH1-10
12" Butterfly
With 6" orifice
Sample Point: □ 20% TVO
◇ 50%
Q
ΔH1-10
3 X 3 CYCLES
KEUFFEL & ESSER CO.
MADE IN U.S.A.

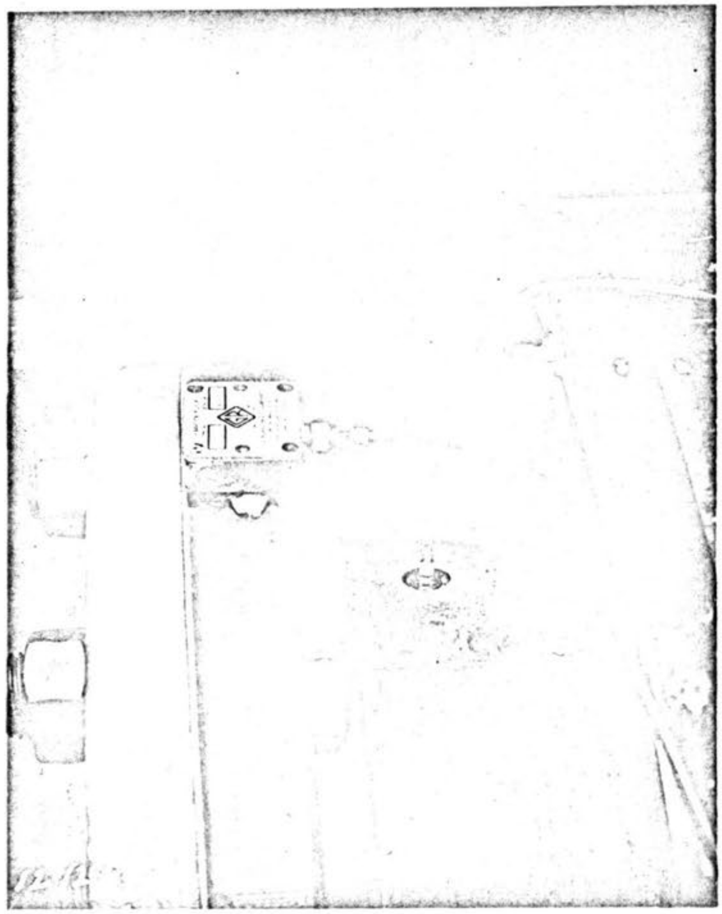
Appendix E Photographs



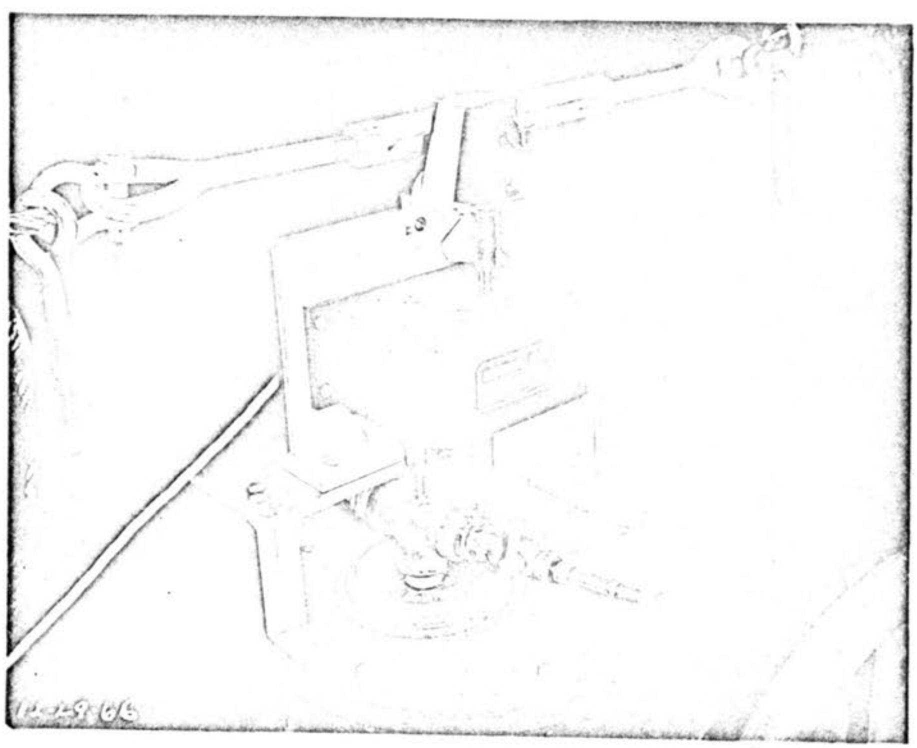
Photograph 1. Nearby Horsetooth Reservoir provides water supply to the Hydro-Machinery Laboratory through a twenty six-inch supply line.



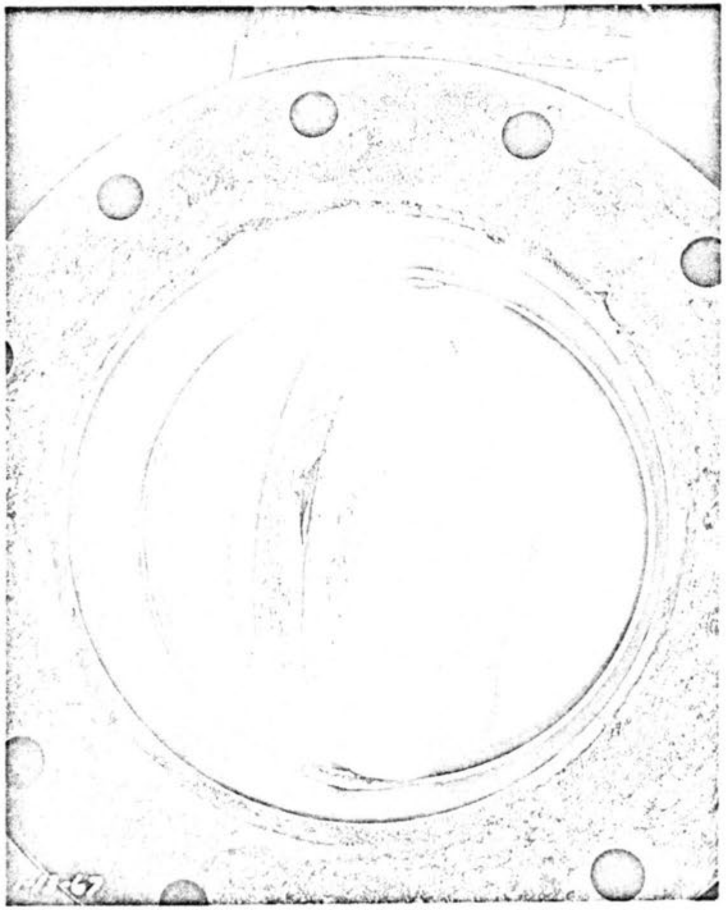
Photograph 2. Vertical and Horizontal Velocity Traverse Ports were located downstream from expansion (note pressure transducers in bottom of pipe).



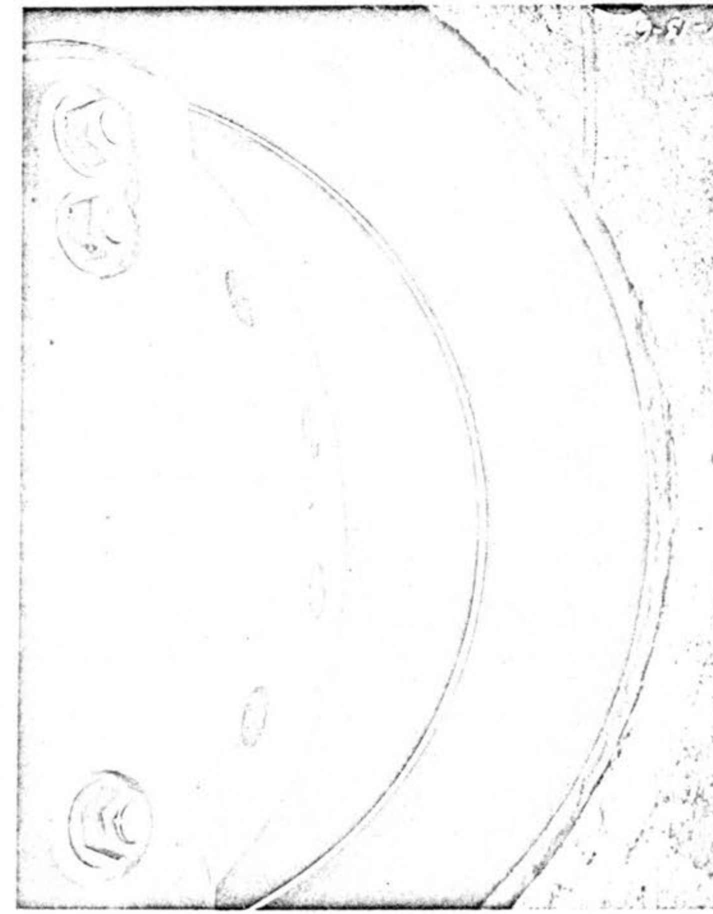
Photograph 3. View of accelerometer on downstream flange and hydrophone in six-inch transition section.



Photograph 4. Potentiometer mounted on shaft of Butterfly Valve to indicate opening percentage (note air injection stem).



Photograph 5. Slight amount of damage on upstream side of Butterfly Valve leaf (noted on left side only).



Photograph 6. Slight amount of damage on downstream side of metal seat (noted on left side only).

Appendix F Transducer and Vibration Meter Information

TRANSDUCER AND VIBRATION METER INFORMATION

Hydrophone

Type	Number	Serial Number	Manufacturer
Flush mounting	LC-70	317	Atlantic Research Corporation Alexandria, Va.

Pressure Transducers

Location	Model or Type	Pressure Range (psi)	Serial Number	Manufacturer*
P_1	APT-25-2C	0-200	32632	Abex
P_2	APT25-2C	0-200	32634	Abex
P_3	4-312-0001	0-150	26290	CEC
P_4	4-312-0001	0-150	24834	CEC
P_5	APT25-2C	0-200	32633	CEC
P_6	4-312-0001	0-150	21329	CEC
P_7	4-312-0001	0-150	21858	CEC
P_8	APT25-2C	0-200	32636	Abex
P_9	APT25-2C	0-200	32638	Abex
P_{10}	4-312-0001	0-150	16878	CEC

Vibration Meter

Type	Acceleration Range	Serial Number	Manufacturer
1553-A	0.3 to 300,000 in/sec^2 (peak to peak) 0.1 to 100,000 in/sec^2 (average)	575	General Radio Co. West Concord, Massachusetts

* Abex, American Brake Shoe, Dynisco Division, Cambridge, Massachusetts
CEC, Consolidated Electrodynamics Corp., Transducer Division, Manrovia, California.