EVALUATION OF THE PERFORMANCE CHARACTERISTICS OF TURBINE-TYPE FLOWMETERS

by

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INTRODUCTION

The purpose of this report is to discuss performance characteristics of various sizes of turbine meters manufactured by three flowmeter companies, Potter Aeronautical, Fischer and Porter, and Waugh. The specific performance characteristics discussed are linearity, range, accuracy and repeatability. Sizes of meters tested ranged from 3/16 to 6 1/2-in. Potter meters, 1/2, 3/4 and 2-in. Fischer and Porter meters and 3/4 and 2-in. Waugh meters.

Linearity

Linearity of a turbine flowmeter is a term used to describe the relationship between the rotating speed of the turbine (frequency) and discharge. It is dependent upon the geometry of the turbine, bearing resistance to the rotor and properties of the fluid flowing through the meter. A flowmeter that exhibits linearity is simple to use because the slope of the frequency-discharge curve is constant and a single calibration factor, K, can be used to determine the relative discharge for any output frequency of the meter.

Range

Linearity of turbine flowmeters is limited practically because of the limitations of the mechanical components of the meter. Bearing friction and energy losses at low discharges and separation and cavitation at high discharges are the principal limitations. The range of discharges between a minimum and maximum discharge displaying linearity is termed the range of the meter.

Accuracy

Accuracy is used to describe the deviation of indicated discharge from actual discharge.

Repeatability

Repeatability is a characteristic which describes how consistently the frequency-discharge relationships can be repeated.

EXPERIMENTAL DATA AND DISCUSSION OF RESULTS

Data used to evaluate the performance characteristics of various flowmeters were obtained from tests made on flowmeters provided by the Martin Company and tested in the Hydraulics Laboratory of Colorado State University. Flowmeters manufactured by the Potter Aeronautical, Fischer and Porter and Waugh Companies were studied.

Potter Aeronautical Flowmeters

Experimental data for Potter meters were obtained for flowmeters ranging in sizes from 3/16 to 6 1/2 inches in diameter. Various models, and where possible, a number of different meters of the same model were used to describe performance characteristics.

Figure 1 in Appendix A shows a typical calibration curve for a 3/16-in. meter. The curve of frequency as a function of discharge (f-G curve) shows a linear relationship. Because of the scale of the coordinates of the graph, it is not easy to determine the accuracy nor the range of the meter. Therefore, a curve of the calibration factor K, as a function of discharge (K-G curve) is shown above the f-G curve. (The abscissa of this curve could be frequency as well as discharge because of the linearity of the flowmeter. For convenience of this curve, discharge is used as the abscissa.)

The dimensions of K are cycles per gallon (c.p.g.). The value of K is the slope of a line (multiplied by 60) connecting a specific point of the frequency-discharge curve with the origin of coordinates. If the calibration curve included the origin, K of each point could be averaged to determine a single value, $\overline{K}$, which would be the average calibration factor for the meter.

As shown in Figure 1, the calibration curve passes very nearly through the origin. However, the curve of calibration factors (K-G curve) shows that an average linear line through all the points determined on the calibration curve does not include the origin as a significant point. Considerable deviation in the values of K are observed for the lower discharges.

According to these performance curves, the characteristics of the model 3/16-308 Potter Aeronautical Flowmeter are:

> The average calibration factor of the meter is $\overline{K}$ = 24,000 c.p.g. The flowmeter is linear in a range of 0.25 to 1.006 g.p.m. (the maximum discharge calibrated) with an accuracy of $\pm$ 1.0 per cent. Repeatability is within 0.2 per cent.

As already discussed, by definition $\overline{K}$ assumes the origin as a significant point. As noted in Figure 1 however the origin is not a significant point in the linear relationship (that is, at frequency = 0, discharge = some finite quanitity). Hence, the fact that an average calibration factor $\overline{K}$ can be used for a range of discharges is only because of the proximity of the origin to the calibration curve. When values of K are determined for the large discharges, the difference between K and the slope of a linear function which best fits the calibration data, is very small. In order to show the difference, a linear function was calculated from the measured data used to plot Fig. 1. The function was of the form

$$f = MG + F_o$$

where

f = frequency in cycles per second

M = slope of the line

G = discharge in gallons per minute

F_o = intercept of the function with the curve $G = 0$.

The computed results were:

$M = 411.45$

$F_o = -2.38$ c.p.s.

or, converting M to cycles per gallon,

$M' = 24,228$ c.p.g.

In a range of 0.25 to 1.0 g.p.m. the accuracy is ± 1.3 per cent. The data of Nov. 7, 1959, give:

$M' = 24,240$ c.p.g.

$F_o = -2.22$ c.p.s.

Accuracy in this case is also within ± 1.3 per cent in a range of 0.25 to 1.0 g.p.m.

Comparisons of the two methods describing Potter flowmeter performance characteristics show that although there is error in the assumption which enables use of $\overline{K}$ as the calibration factor for the meter, its use enables greater accuracy in determining discharge than does M' within a specified meter range. The lower limit of the meter range is arbitrarily set at the discharge when the accuracy of the meter is exceeded.

The curves of Fig. 1 are only for a model 3/16-308 flowmeter, serial No. GLMD-10. Fig. 2 shows comparative curves of calibration factor K for different meters of the same model. Note that the values of $\overline{K}$ differ for each meter.

Figs. 3 through 15 show performance curves of flow meter models 3/8-405, 1/2-308, 3/4-80, 3/4-308, 1 1/2-354A, 2-353, 3-349, 4-317, 4-353, 4 1/2-317, 5 1/2-317, 6-353, and 6 1/2-317 respectively. Comparative performance of various meters of the same model are shown in Figures 16 to 27. These performance curves show that the frequency-discharge curve of all the meters tested pass very nearly through the origin of coordinates. Because of this significant meter characteristic, it is more advantageous to use the calibration factor $\overline{K}$ and to limit the meter range, than it is to apply a linear function if an accuracy less than $\pm$ 1.0 per cent is required. Each flowmeter exhibits different characteristics depending upon both size and model. The smaller sizes are generally more variable between different meters than the larger sizes, but in all cases the variance requires that each flowmeter be calibrated separately. It is to be noted further in Figs. 3 to 15 that the same meter recalibrated after some amount of use, shows differences in the average calibration factor. Therefore, it would appear desirable to recalibrate meters from time to time to establish a new calibration curve so that the required accuracy can be maintained.

Fischer and Porter Flowmeters

Experimental data for Fischer and Porter flowmeters were obtained for meters 1/2, 3/4, and 2-inches in size. Performance curves for these meters are shown in Figs. 28 to 31 of Appendix B. There is considerable variation in the value of K for each point calibrated for the 1/2-inch meter of Fig. 28. Because of the constant change in the values of K with discharge, there is no average value of $\overline{K}$ applicable to any range of discharge. Using the concept of calibration factor K , it would be necessary to use a specific K for each frequency output. Note also the difference in meter performance at a different fluid temperature. The values of M' and F_o are also shown on the Figure. Using these values and the calibration of December 26, 1957, the variations between the measured values and the linear function are $\pm$ 3.0 per cent in a range of 1 to 10 g.p.m.

The performance curves for the flowmeter model 10C1505, size 3/4-23 are shown in Fig. 29. Using calibration factor K, linear operation exists in a flow range from 4.5 to 20 g.p.m. with an accuracy of $\pm$ 1.0 per cent. The average calibration factor $\overline{K}$ is 1505 c.p.g. For the same calibration data M' = 1507.9 c.p.g. and F_o = .27 c.p.s. With an accuracy of $\pm$ 0.9 per cent in a flow range of 2.4 to 23 g.p.m. The performance characteristics shown in Fig. 29 are with water as the metered fluid. The performance characteristics of the same meter using hydraulic oil of larger kinematic viscosity than water, are shown in Fig. 30. Comparison of meter performance with water and oil shows that the viscosity of the metered fluid has considerable effect. (The effect of viscosity are discussed in a separate report). For this meter, an increase in the viscosity decreased the range and decreased frequency output. For the hydraulic oil

$\overline{K}$ = 1505 c.p.g. in a range from 10 to 22 g.p.m,
M' = 1536.34 c.p.g. and F_o = -12.42 c.p.s. in a range from 4 to 24 g.p.m.

The accuracy of the meter using the linear function for measuring hydraulic oil is $\pm$ 2.0 per cent.

The performance curves of a model 10C1505 2-inch Fischer and Porter meter are shown in Fig. 31. The general characteristics discussed for the 1/2 and 3/4-inch meter pertains also to the 2-inch flowmeter.

Waugh Meters

Performance characteristics of Waugh meters were determined for the 3/4 and 2-inch meters. Fig. 32 of Appendix C shows frequency-discharge and K-discharge curves for a 3/4 inch meter model MT110-2511. The calibrating fluid was hydraulic oil at 100°F. Note that because the f-G curve is displaced from the origin of coordinates, the values of K change significantly and constantly with discharge. The value of M and F_o are 1753.4 c.p.g. and -8.08 c.f.s. respectively. Accuracy of the meter is within ± 0.5 per cent using the linear relationship in a flow range of 3.8 to 26 g.p.m. A single factor $\bar{K}$ cannot be applied to the meter; either specific values of K for different discharges, or values of M' and F_o could be used for calculation of discharge. Fig. 33 shows similar characteristics for a 2-inch flowmeter.

SUMMARY AND CONCLUSIONS

Turbine-type flowmeters were tested for performance characteristics. In a specific flow range and within a specified accuracy, all the flowmeters show linearity between frequency output and discharge. Either of two methods may be used to determine a single calibration factor for a turbine meter. One method is to use an average value $\bar{K}$ which may be determined from a curve of K as a function of either discharge or frequency output. The value of K is the slope of an imaginary line from the origin of coordinates to the points on the f-G curve. The second method is to determine by linear regression, a line to fit the set of measured data. Constants M' and F_o of the linear relationship could then be used to calculate the discharge from measured frequency.

The results of the study shows that for Potter Aeronautical flowmeters of the sizes tested, the first method is perhaps superior if an accuracy of ± 1.0 per cent is required. This applies particularly to the small meters. For the larger meters, either method will give satisfactory results.

Use of an average calibration factor $\bar{K}$ limits the range for sizes 1/2 and 3/4-inch Fischer and Porter flowmeters. The linear expression for the calibration curve will extend the range of the meter, but with sacrifice of accuracy. In this case, the only recourse is to use different values of K for each meter frequency to determine the discharge. Either $\bar{K}$ or the linear expression may be used for the 2-inch Fischer and Porter meter.

The Waugh flowmeters of 3/4 and 2-inch sizes tested show linear characteristics. The linear function results in a wider range for the 3/4-inch meter than use of $\bar{K}$. Either method will give discharge measurements within $\pm$ 1 per cent for the 2-inch meter.

APPENDIX A

POTTER AERONAUTICAL FLOWMETERS

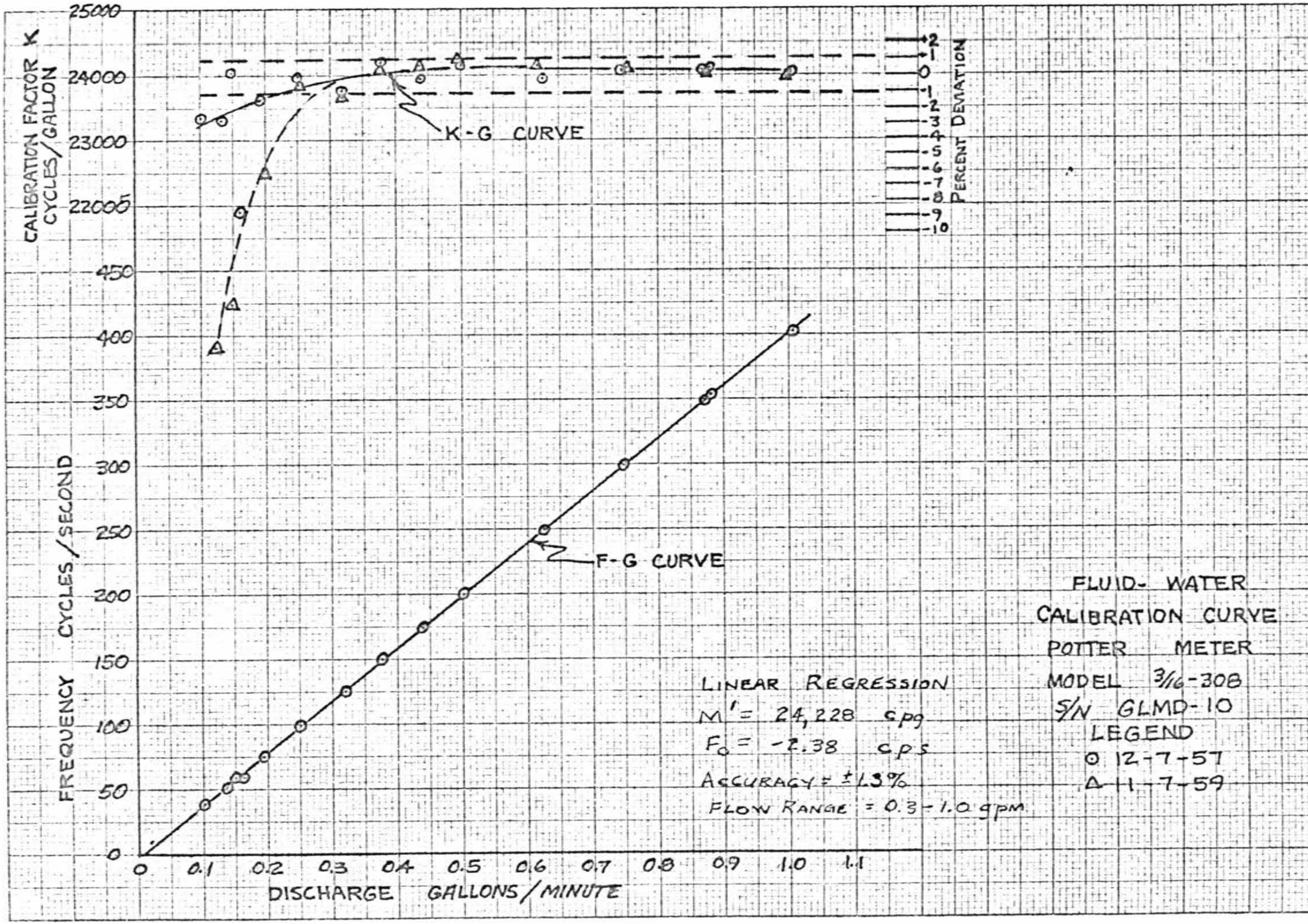

CALIBRATION FACTOR K
CYCLES/GALLON
25000
24000
23000
22000
450
400
350
300
250
200
150
100
50
0
FREQUENCY CYCLES/SECOND
+2
+1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
PERCENT DEVIATION
K-G CURVE
F-G CURVE
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
DISCHARGE GALLONS/MINUTE
LINEAR REGRESSION
M' = 24,228 cpg
F₀ = -2.38 cps
ACCURACY = ±1.3%
FLOW RANGE = 0.3-1.0 gpm
FLUID- WATER
CALIBRATION CURVE
POTTER METER
MODEL 3/16-308
S/N GLMD-10
LEGEND
⊙ 12-7-57
Δ 11-7-59

FIG. 1

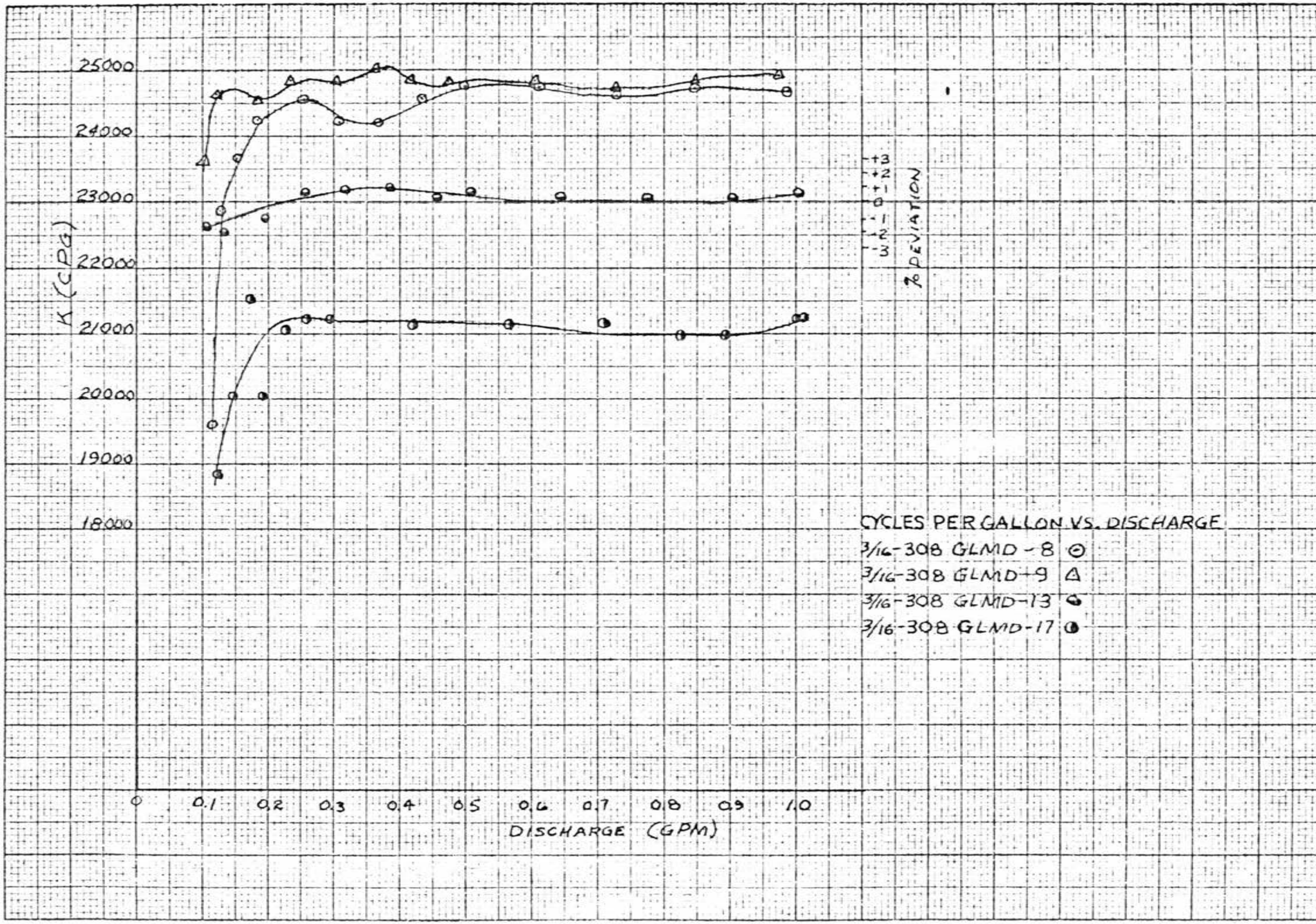
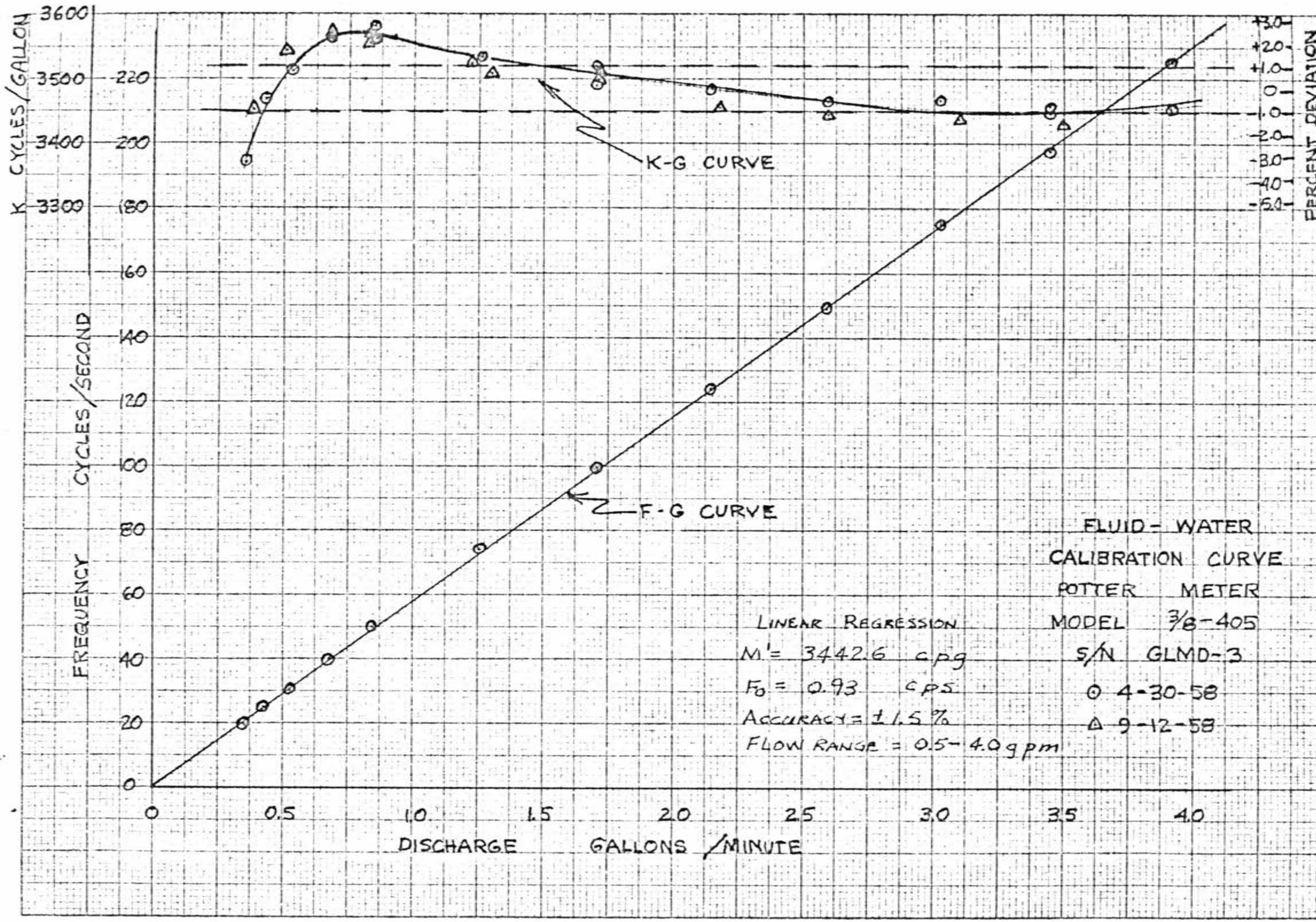

25000
24000
23000
22000
21000
20000
19000
18000
K (CPG)
+3
+2
+1
0
-1
-2
-3
% DEVIATION
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
DISCHARGE (GPM)
CYCLES PER GALLON VS. DISCHARGE
3/16-308 GLMD-8
3/16-308 GLMD-9
3/16-308 GLMD-13
3/16-308 GLMD-17

FIG. 2



K CYCLES/GALLON
3600
3500
3400
3300
FREQUENCY CYCLES/SECOND
220
200
180
160
140
120
100
80
60
40
20
0
PERCENT DEVIATION
+3.0
+2.0
+1.0
0
-1.0
-2.0
-3.0
-4.0
-5.0
K-G CURVE
F-G CURVE
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
DISCHARGE GALLONS /MINUTE
FLUID - WATER
CALIBRATION CURVE
POTTER METER
MODEL 3/8-405
S/N GLMD-3
⊙ 4-30-58
△ 9-12-58
LINEAR REGRESSION
M' = 3442.6 cpg
F0 = 0.93 cps
ACCURACY = ±1.5 %
FLOW RANGE = 0.5-4.0 gpm

FIG. 3

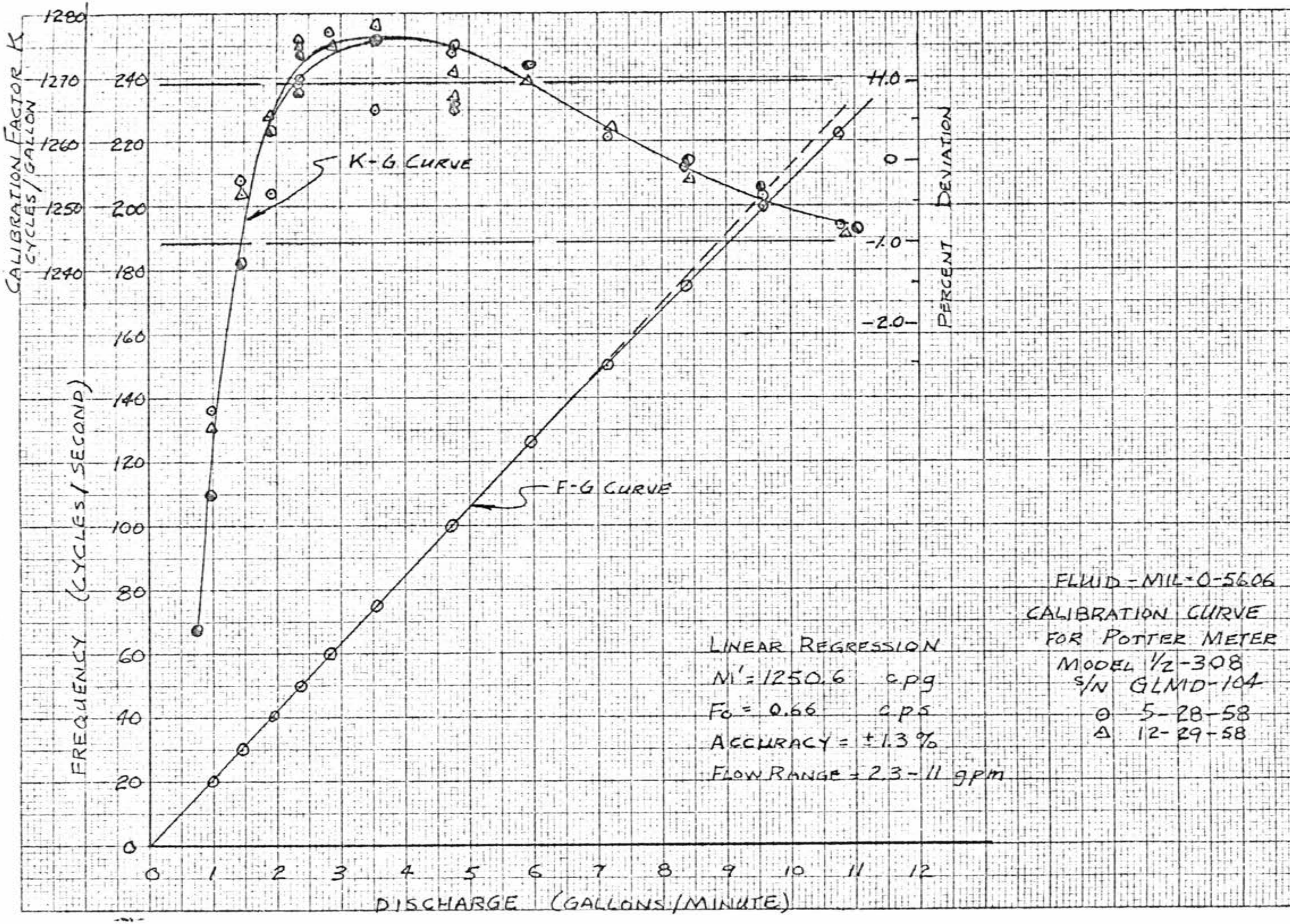
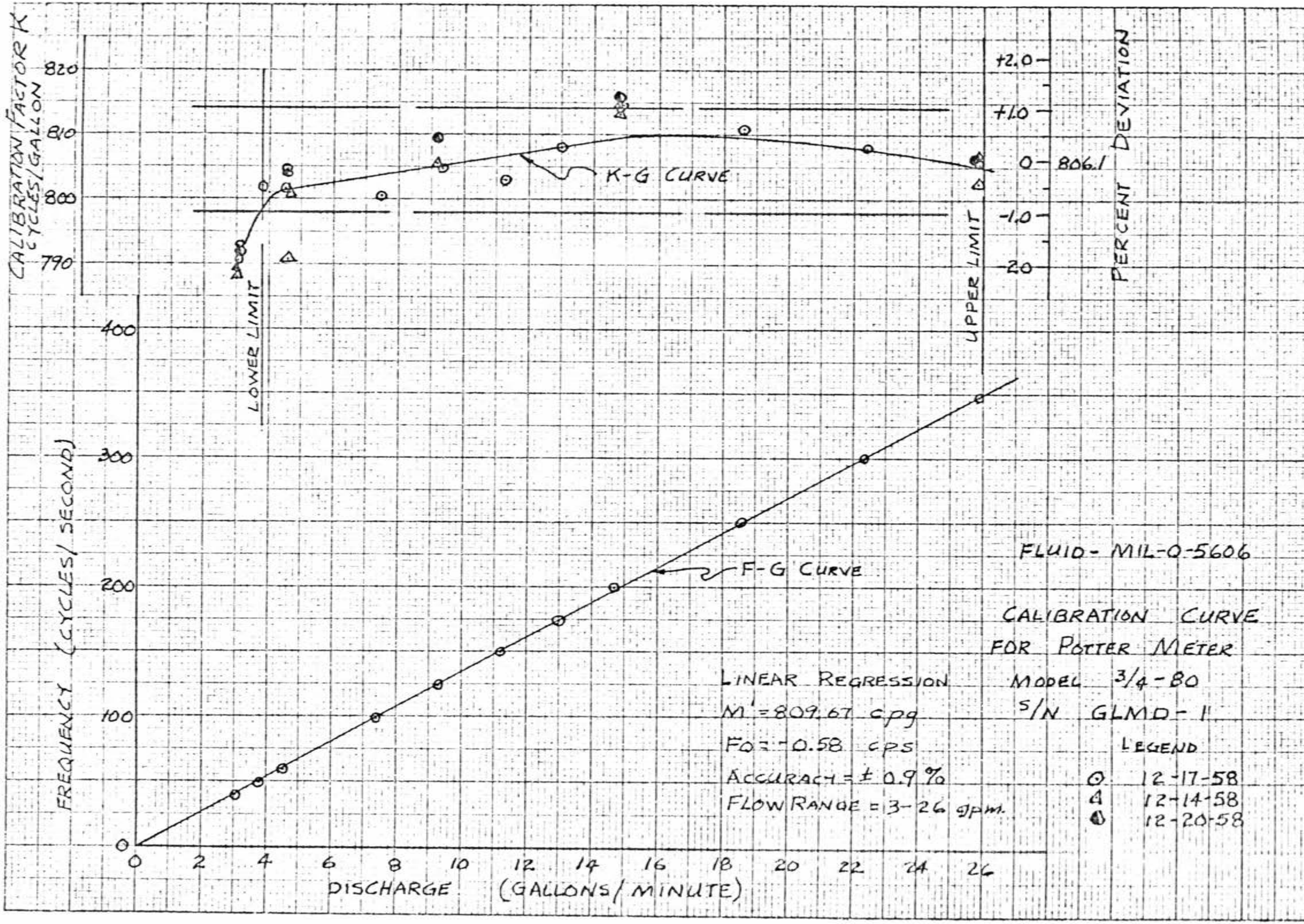

CALIBRATION FACTOR K
CYCLES / GALLON
1280
1270
1260
1250
1240
240
220
200
180
160
140
120
100
80
60
40
20
0
K-G CURVE
F-G CURVE
+1.0
0
-1.0
-2.0
PERCENT DEVIATION
FREQUENCY (CYCLES / SECOND)
0 1 2 3 4 5 6 7 8 9 10 11 12
DISCHARGE (GALLONS/MINUTE)
LINEAR REGRESSION
N' = 1250.6 cpg
Fo = 0.66 cps
ACCURACY = ±1.3 %
FLOW RANGE = 2.3 - 11 gpm
FLUID - MIL-O-5606
CALIBRATION CURVE
FOR POTTER METER
MODEL 1/2-308
S/N GLMD-104
⊖ 5-28-58
Δ 12-29-58

FIG. 4



CALIBRATION FACTOR K CYCLES/GALLON
820
810
800
790
+2.0
+1.0
0
806.1
-1.0
-2.0
PERCENT DEVIATION
K-G CURVE
LOWER LIMIT
UPPER LIMIT
400
300
200
100
0
FREQUENCY (CYCLES/ SECOND)
F-G CURVE
0 2 4 6 8 10 12 14 16 18 20 22 24 26
DISCHARGE (GALLONS/ MINUTE)
FLUID - MIL-O-5606
CALIBRATION CURVE
FOR POTTER METER
MODEL 3/4-80
S/N GLMD-1
LINEAR REGRESSION
M' = 809.67 cpg
Fo = -0.58 cps
ACCURACY = ± 0.9 %
FLOW RANGE = 3-26 gpm.
LEGEND
12-17-58
12-14-58
12-20-58

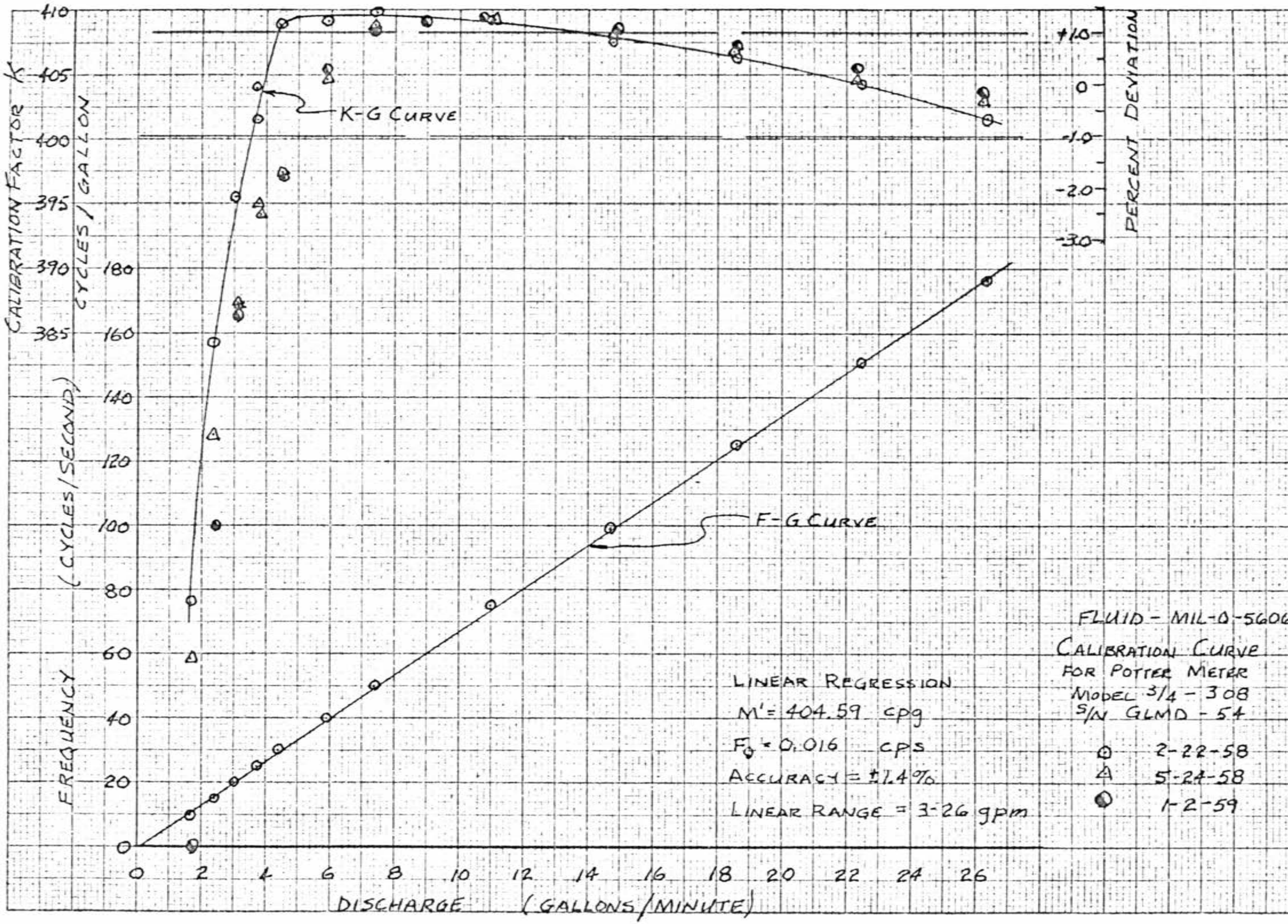

CALIBRATION FACTOR K
CYCLES / GALLON
410
405
400
395
390
385
PERCENT DEVIATION
+1.0
0
-1.0
-2.0
-3.0
K-G CURVE
FREQUENCY (CYCLES/SECOND)
180
160
140
120
100
80
60
40
20
0
F-G CURVE
DISCHARGE (GALLONS/MINUTE)
0 2 4 6 8 10 12 14 16 18 20 22 24 26
LINEAR REGRESSION
M' = 404.59 cpg
F0 = 0.016 cps
ACCURACY = ±1.4%
LINEAR RANGE = 3-26 gpm
FLUID - MIL-O-5606
CALIBRATION CURVE
FOR POTTER METER
MODEL 3/4 - 308
S/N GLMD - 54
2-22-58
5-24-58
1-2-59

Fig. 6

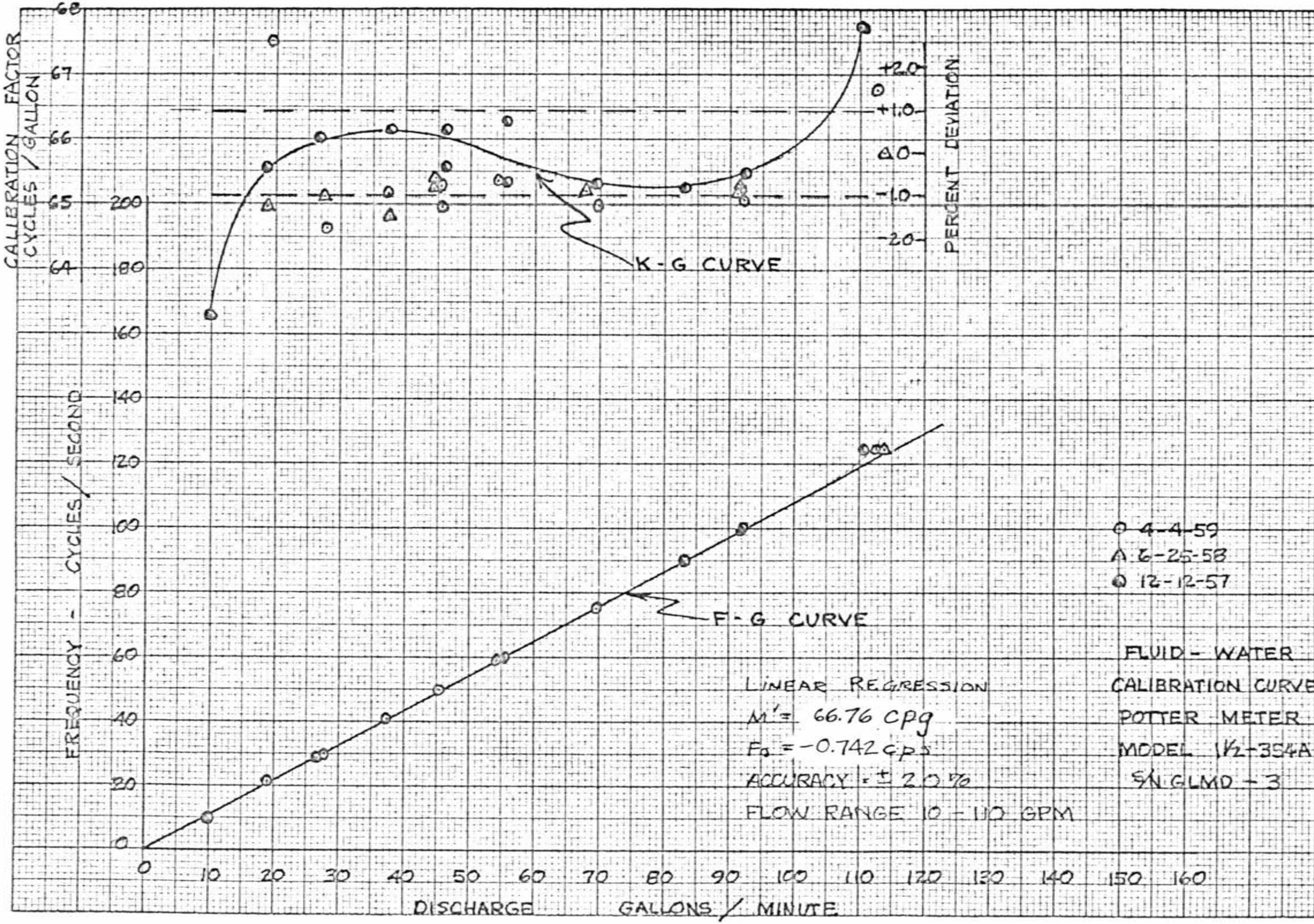
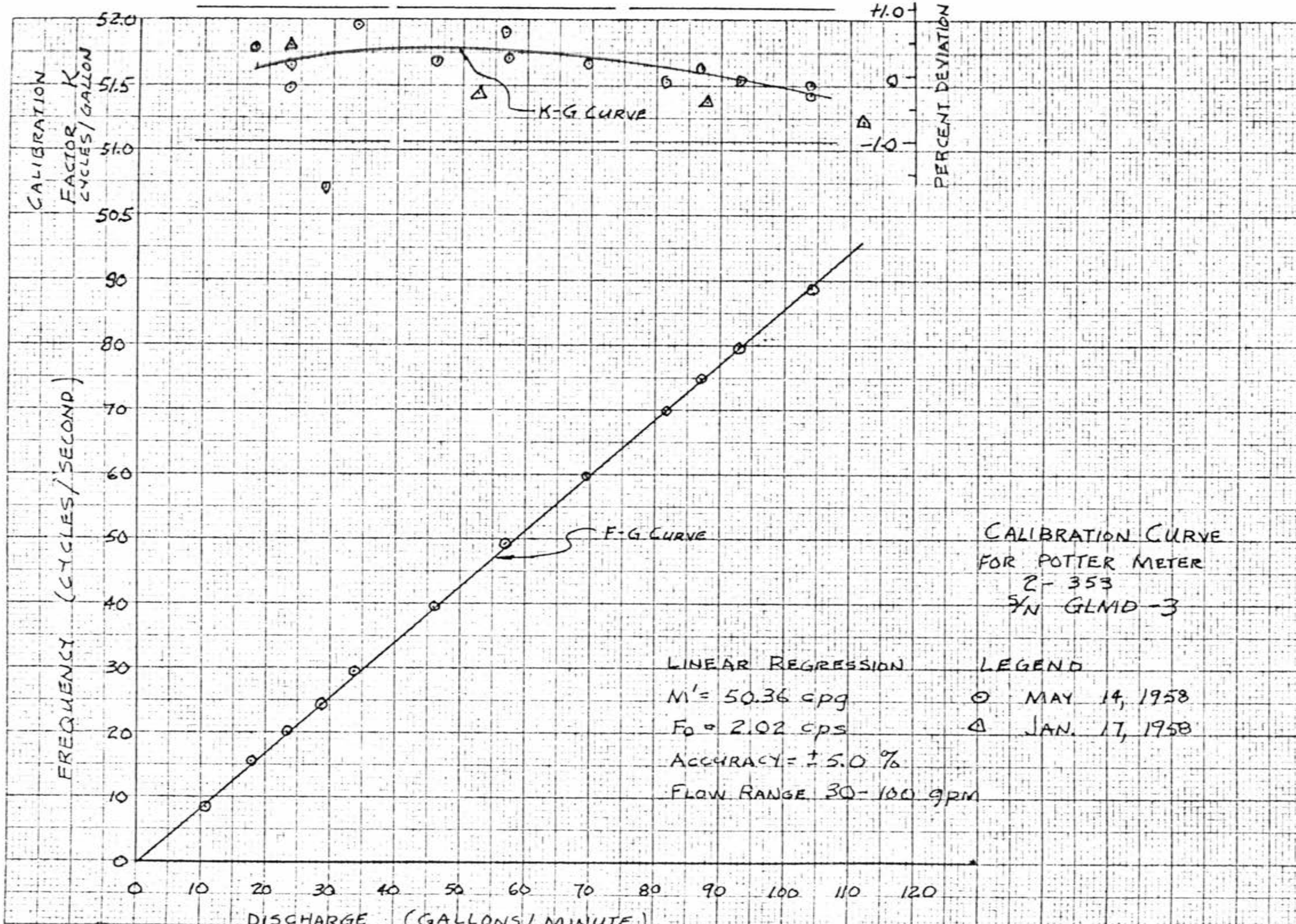

CALIBRATION FACTOR
CYCLES / GALLON
PERCENT DEVIATION
K-G CURVE
F-G CURVE
FREQUENCY - CYCLES / SECOND
DISCHARGE GALLONS / MINUTE
4-4-59
6-25-58
12-12-57
FLUID - WATER
CALIBRATION CURVE
POTTER METER
MODEL 1½-354A
S/N GLMD - 3
LINEAR REGRESSION
M' = 66.76 cpg
Fo = -0.742 cps
ACCURACY ± 2.0 %
FLOW RANGE 10 - 110 GPM

Fig. 7



CALIBRATION FACTOR K CYCLES/GALLON
52.0
51.5
51.0
50.5
+1.0
0
-1.0
PERCENT DEVIATION
K-G CURVE
F-G CURVE
FREQUENCY (CYCLES/SECOND)
90
80
70
60
50
40
30
20
10
0
0 10 20 30 40 50 60 70 80 90 100 110 120
DISCHARGE (GALLONS/MINUTE)
CALIBRATION CURVE
FOR POTTER METER
2-353
S/N GLMD-3
LINEAR REGRESSION
M' = 50.36 cpg
Fo = 2.02 cps
ACCURACY = ± 5.0 %
FLOW RANGE 30-100 gpm
LEGEND
⊙ MAY 14, 1958
△ JAN. 17, 1958

FIG. 8

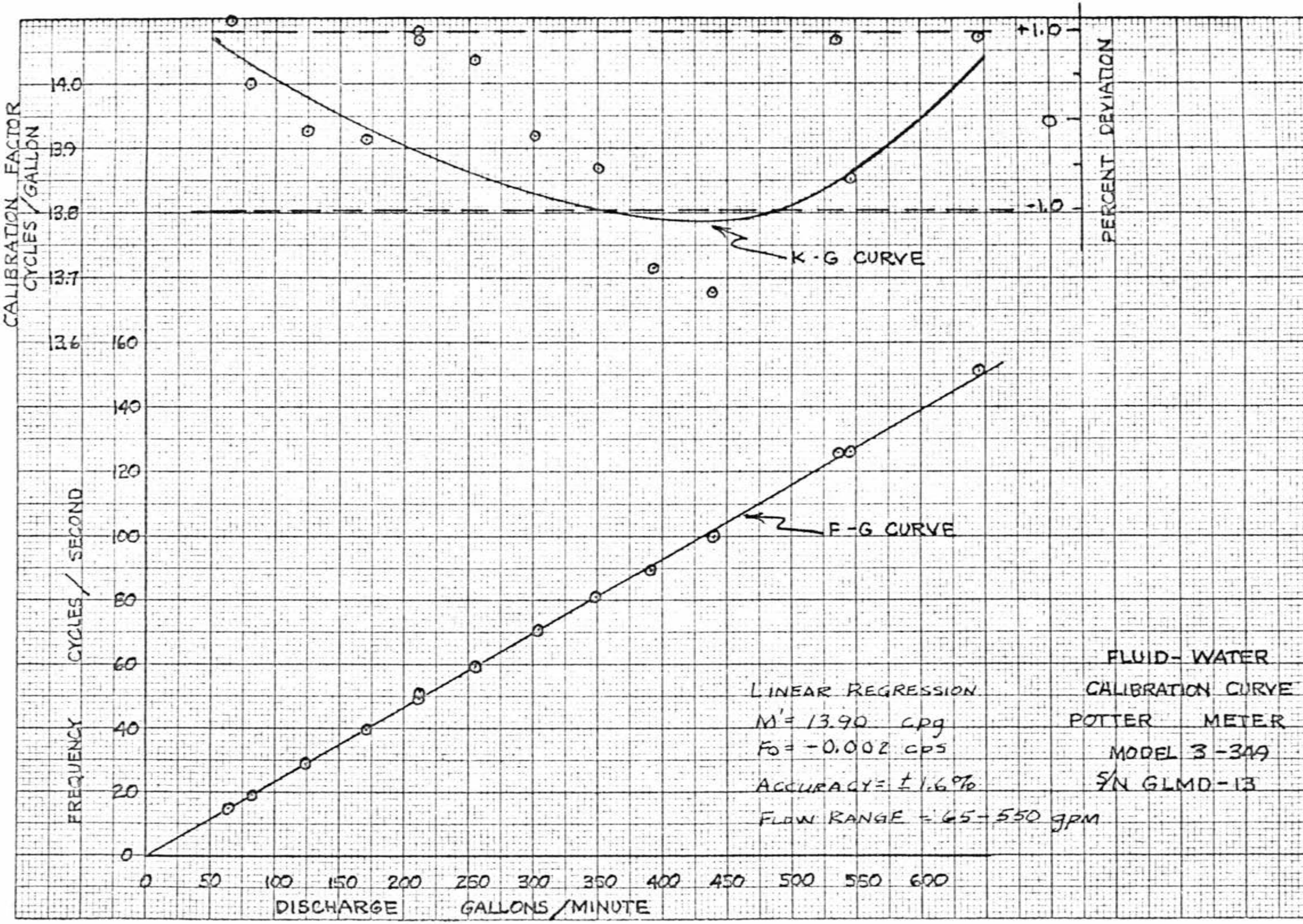
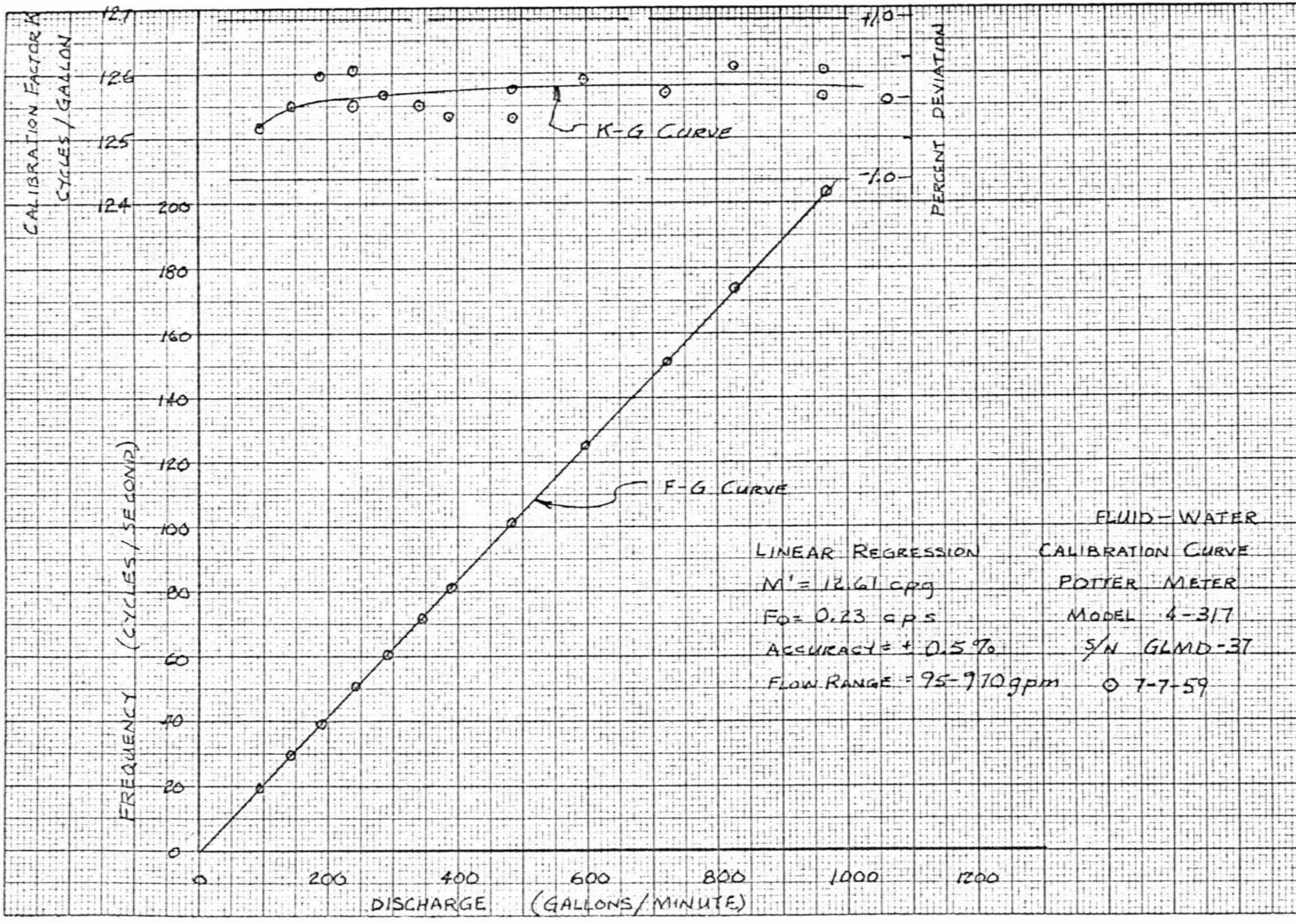
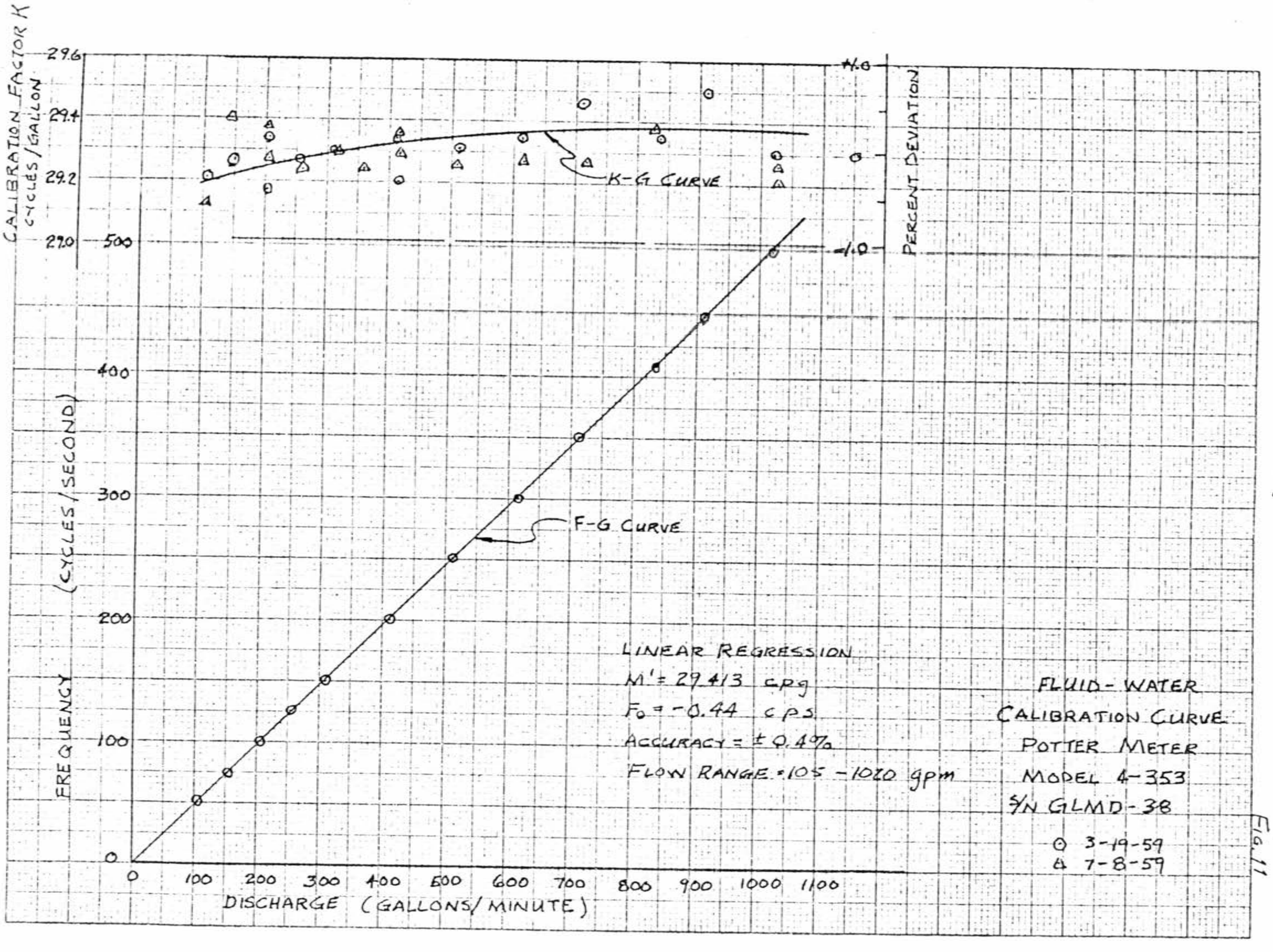

CALIBRATION FACTOR CYCLES / GALLON
14.0
13.9
13.8
13.7
13.6
PERCENT DEVIATION
+1.0
0
-1.0
K-G CURVE
F-G CURVE
FREQUENCY CYCLES / SECOND
160
140
120
100
80
60
40
20
0
DISCHARGE GALLONS / MINUTE
0
50
100
150
200
250
300
350
400
450
500
550
600
LINEAR REGRESSION
M' = 13.90 cpg
Fo = -0.002 cps
ACCURACY = ± 1.6%
FLOW RANGE = 65-550 gpm
FLUID - WATER
CALIBRATION CURVE
POTTER METER
MODEL 3-349
S/N GLMD-13

Fig. 9



CALIBRATION FACTOR K
CYCLES / GALLON
12.7
12.6
12.5
12.4
+1.0
0
-1.0
PERCENT DEVIATION
K-G CURVE
FREQUENCY (CYCLES / SECOND)
200
180
160
140
120
100
80
60
40
20
0
F-G CURVE
0
200
400
600
800
1000
1200
DISCHARGE (GALLONS / MINUTE)
FLUID - WATER
LINEAR REGRESSION
M' = 12.61 cpg
F0 = 0.23 cps
ACCURACY = ± 0.5%
FLOW RANGE = 95-970 gpm
CALIBRATION CURVE
POTTER METER
MODEL 4-317
S/N GLMD-37
⊙ 7-7-59

FIG 10



CALIBRATION FACTOR K
CYCLES/GALLON
29.6
29.4
29.2
29.0
+1.0
0
-1.0
PERCENT DEVIATION
K-G CURVE
FREQUENCY (CYCLES/SECOND)
500
400
300
200
100
0
F-G CURVE
0 100 200 300 400 500 600 700 800 900 1000 1100
DISCHARGE (GALLONS/MINUTE)
LINEAR REGRESSION
M' = 29.413 cpg
F₀ = -0.44 cps
ACCURACY = ± 0.4%
FLOW RANGE = 105 - 1020 gpm
FLUID - WATER
CALIBRATION CURVE
POTTER METER
MODEL 4-353
S/N GLMD-38
3-19-59
7-8-59

Fig. 11

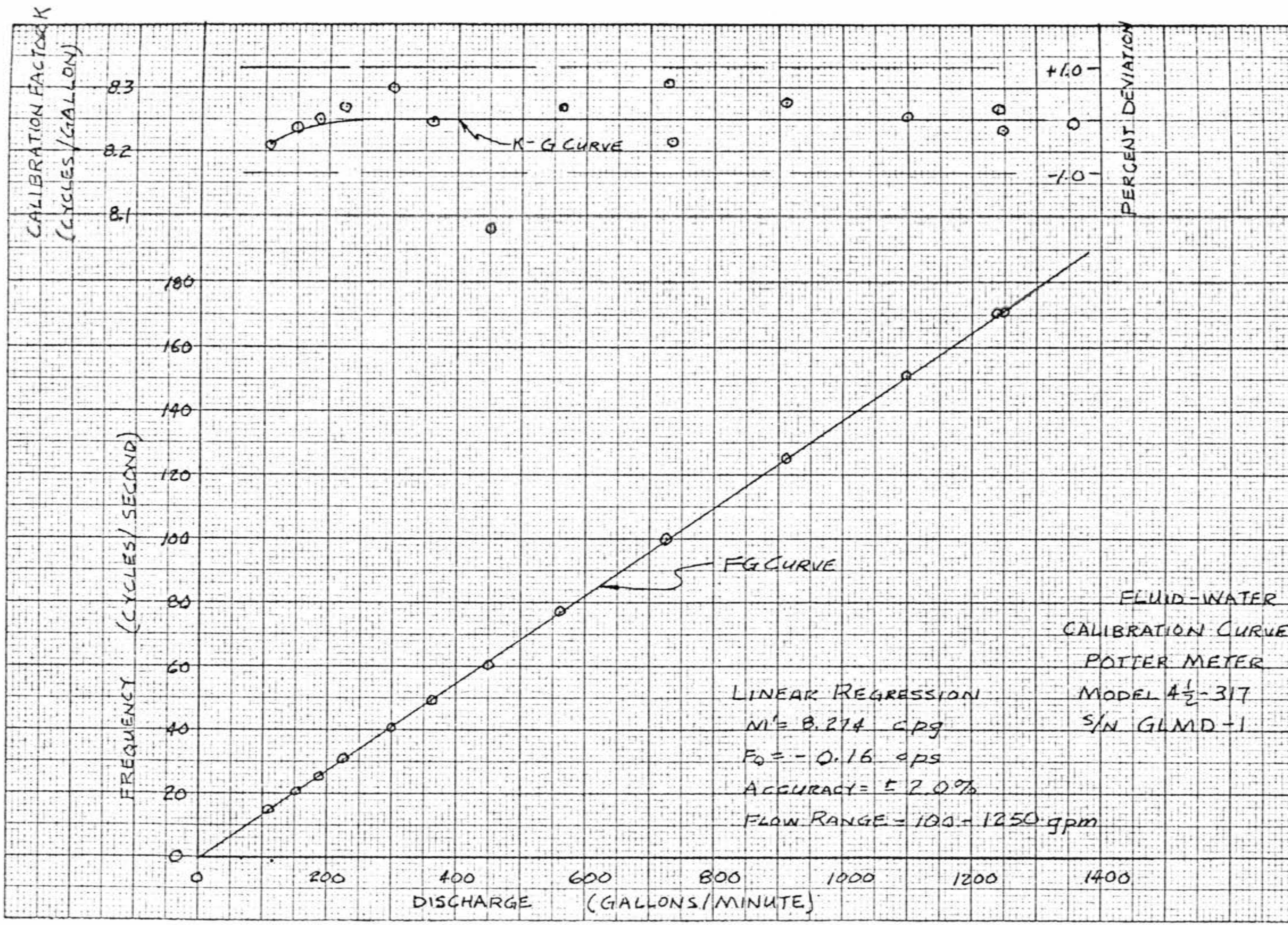
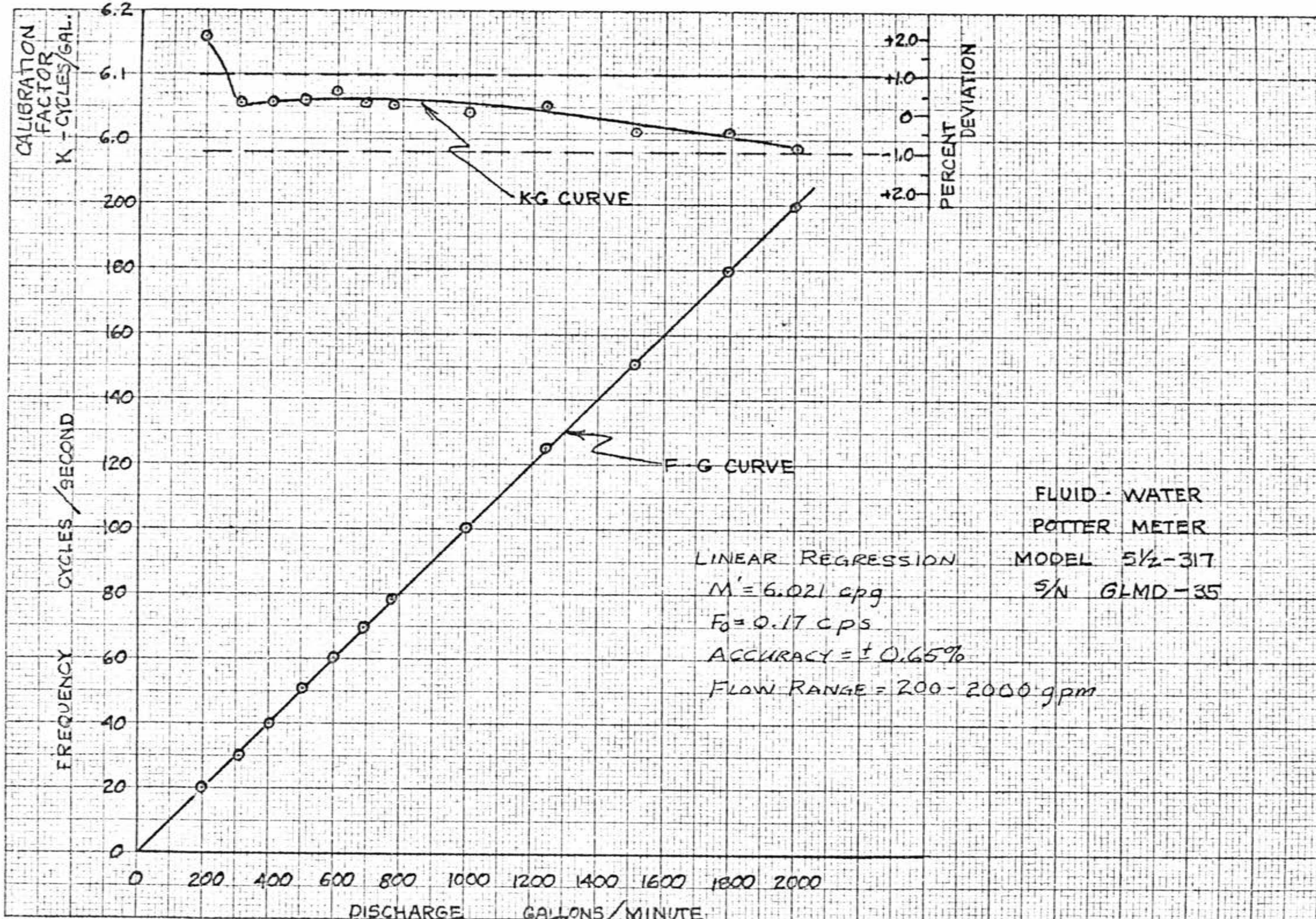

CALIBRATION FACTOR K
(CYCLES/GALLON)
8.3
8.2
8.1
+1.0
-1.0
PERCENT DEVIATION
K-G CURVE
FREQUENCY (CYCLES/SECOND)
180
160
140
120
100
80
60
40
20
0
FG CURVE
DISCHARGE (GALLONS/MINUTE)
0
200
400
600
800
1000
1200
1400
FLUID-WATER
CALIBRATION CURVE
POTTER METER
MODEL 4½-317
S/N GLMD-1
LINEAR REGRESSION
M' = 8.274 cpg
F0 = -0.16 cps
ACCURACY = ± 2.0%
FLOW RANGE = 100-1250 gpm

FIG. 12



CALIBRATION FACTOR K - CYCLES/GAL.
6.2
6.1
6.0
+2.0
+1.0
0
-1.0
+2.0
PERCENT DEVIATION
K-G CURVE
200
180
160
140
120
100
80
60
40
20
0
FREQUENCY CYCLES/SECOND
F-G CURVE
FLUID: WATER
POTTER METER
MODEL 5½-317
S/N GLMD-35
LINEAR REGRESSION
M' = 6.021 cpg
F0 = 0.17 cps
ACCURACY = ± 0.65%
FLOW RANGE = 200 - 2000 gpm
0 200 400 600 800 1000 1200 1400 1600 1800 2000
DISCHARGE GALLONS/MINUTE

FIG. 13

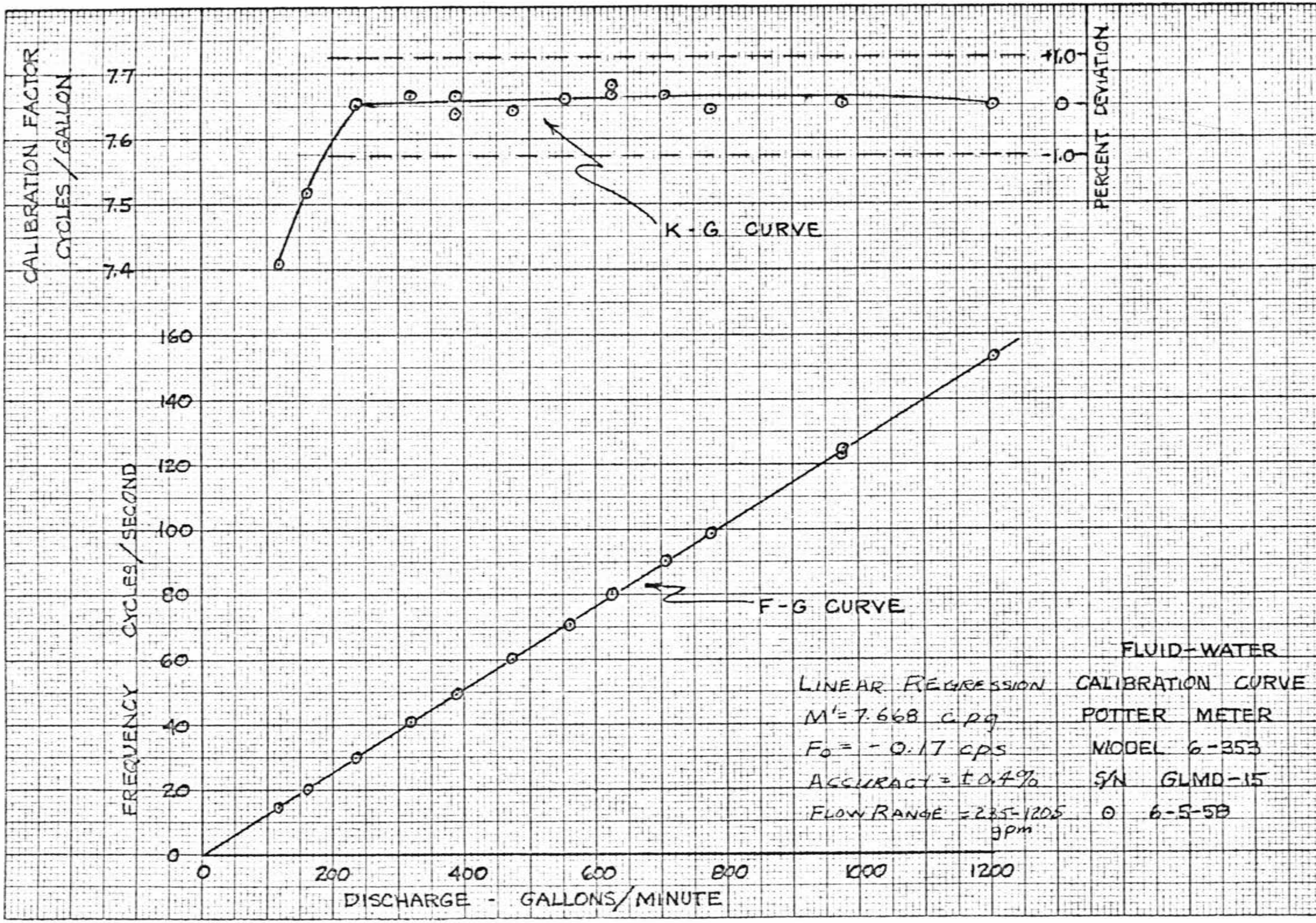
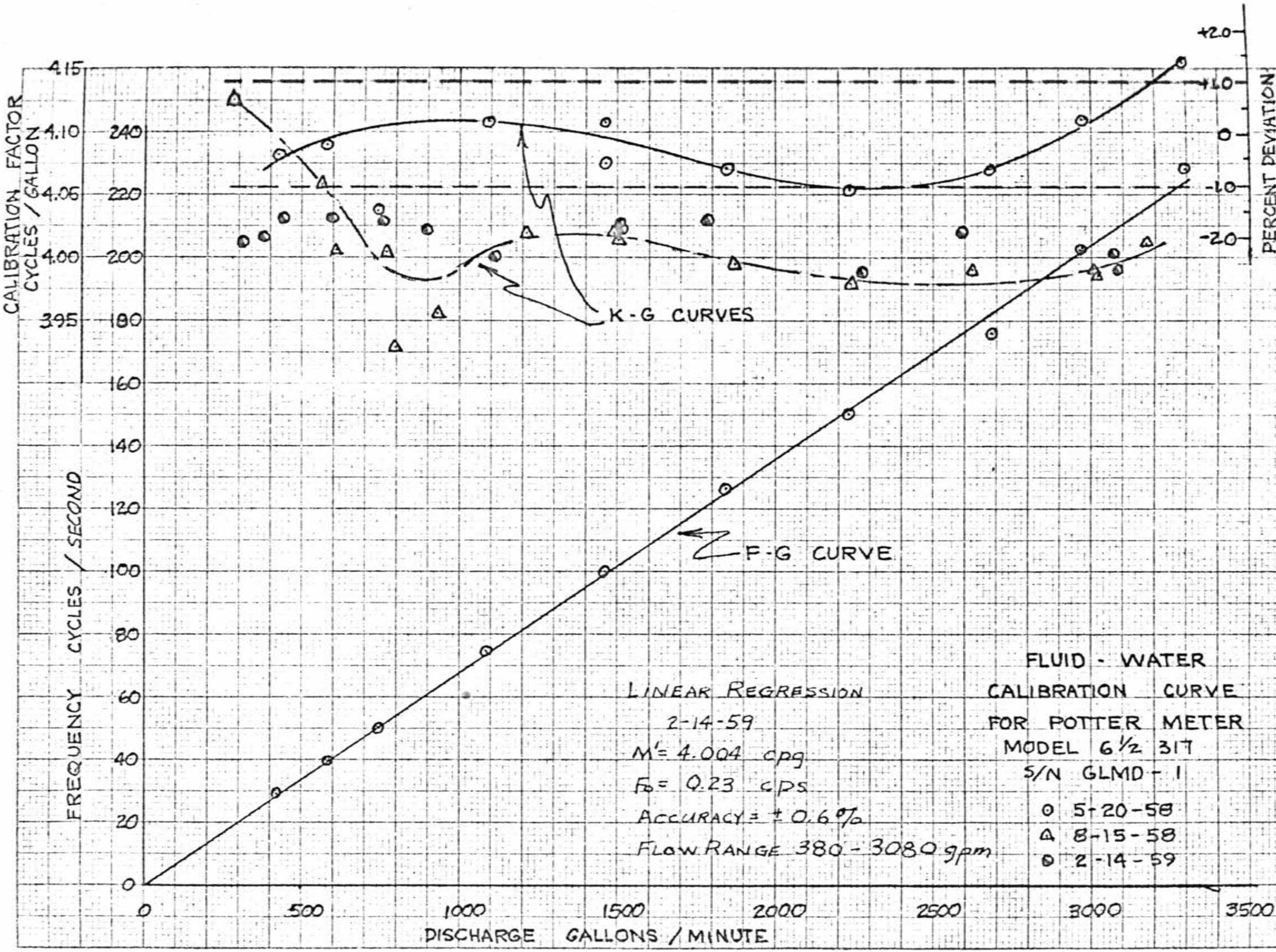

CALIBRATION FACTOR CYCLES / GALLON
7.7
7.6
7.5
7.4
+1.0
0
-1.0
PERCENT DEVIATION
K-G CURVE
FREQUENCY CYCLES / SECOND
160
140
120
100
80
60
40
20
0
F-G CURVE
0
200
400
600
800
1000
1200
DISCHARGE - GALLONS/MINUTE
FLUID-WATER
LINEAR REGRESSION
M' = 7.668 cpg
F0 = -0.17 cps
ACCURACY = ±0.4%
FLOW RANGE = 235-1205 gpm
CALIBRATION CURVE
POTTER METER
MODEL 6-353
S/N GLMD-15
⊙ 6-5-58

FIG. 14



CALIBRATION FACTOR CYCLES / GALLON
PERCENT DEVIATION
FREQUENCY CYCLES / SECOND
DISCHARGE GALLONS / MINUTE
K-G CURVES
F-G CURVE
LINEAR REGRESSION
2-14-59
M' = 4.004 cpg
Fo = 0.23 cps
ACCURACY = ± 0.6%
FLOW RANGE 380 - 3080 gpm
FLUID - WATER
CALIBRATION CURVE
FOR POTTER METER
MODEL 6½ 317
S/N GLMD - 1
o 5-20-58
Δ 8-15-58
⊙ 2-14-59

FIG. 15

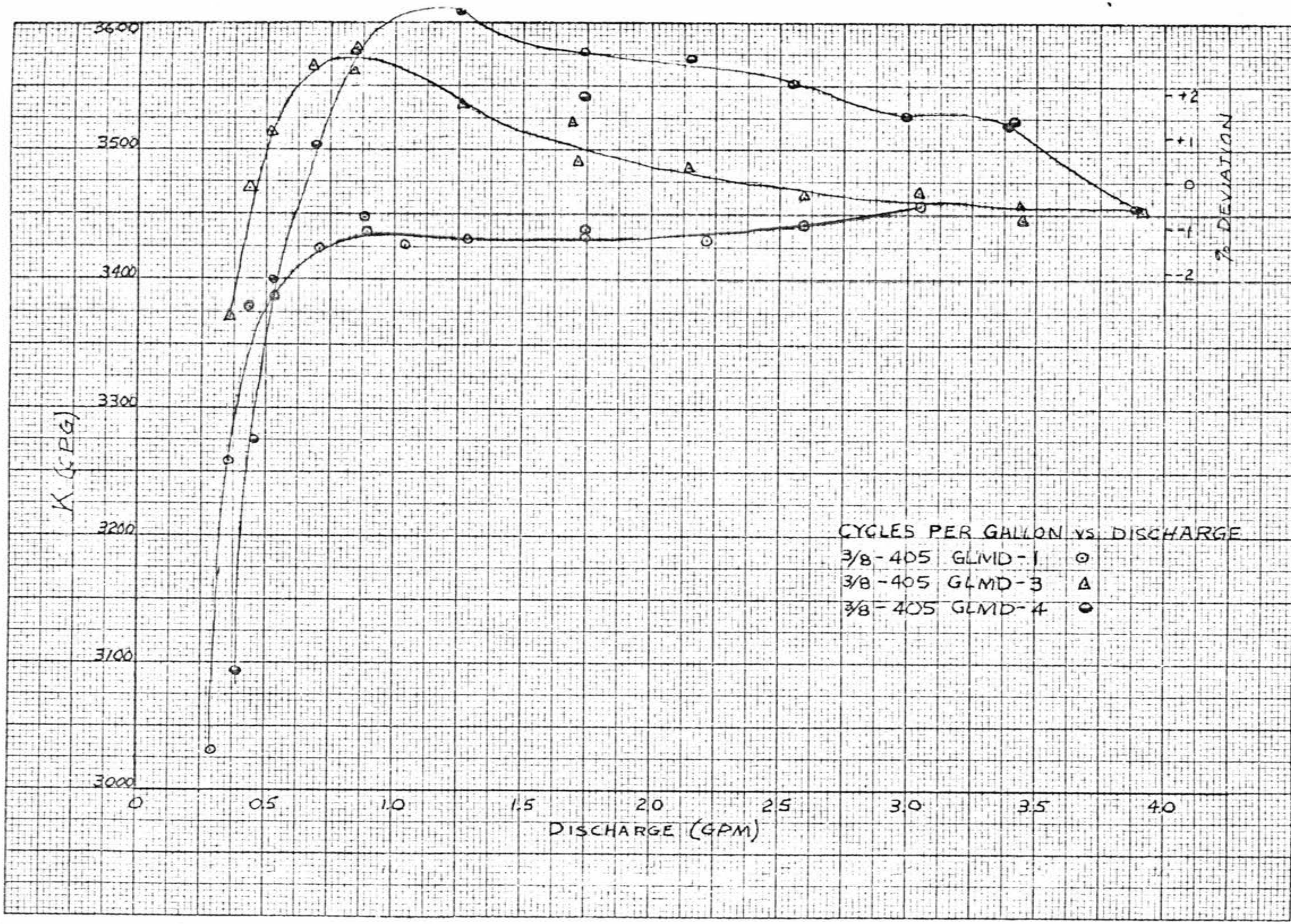

3600
3500
3400
3300
3200
3100
3000
K (CPG)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
DISCHARGE (GPM)
+2
+1
0
-1
-2
% DEVIATION
CYCLES PER GALLON VS. DISCHARGE
3/8-405 GLMD-1 ⊙
3/8-405 GLMD-3 Δ
3/8-405 GLMD-4

FIG. 16

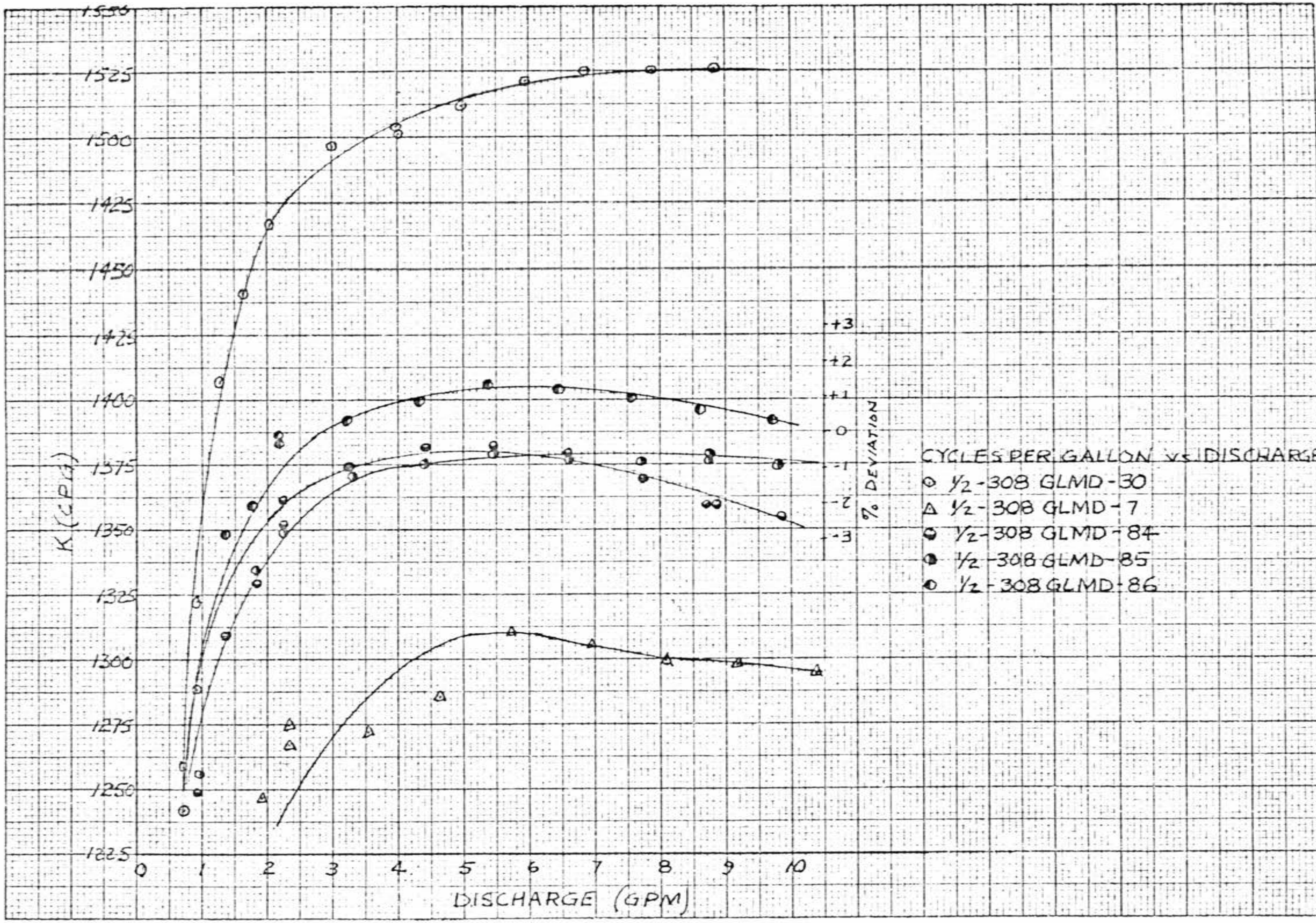

K (CPG)
1525
1500
1475
1450
1425
1400
1375
1350
1325
1300
1275
1250
1225
0 1 2 3 4 5 6 7 8 9 10
DISCHARGE (GPM)
% DEVIATION
+3
+2
+1
0
-1
-2
-3
CYCLES PER GALLON vs DISCHARGE
1/2-308 GLMD-30
1/2-308 GLMD-7
1/2-308 GLMD-84
1/2-308 GLMD-85
1/2-308 GLMD-86

Fig. 17

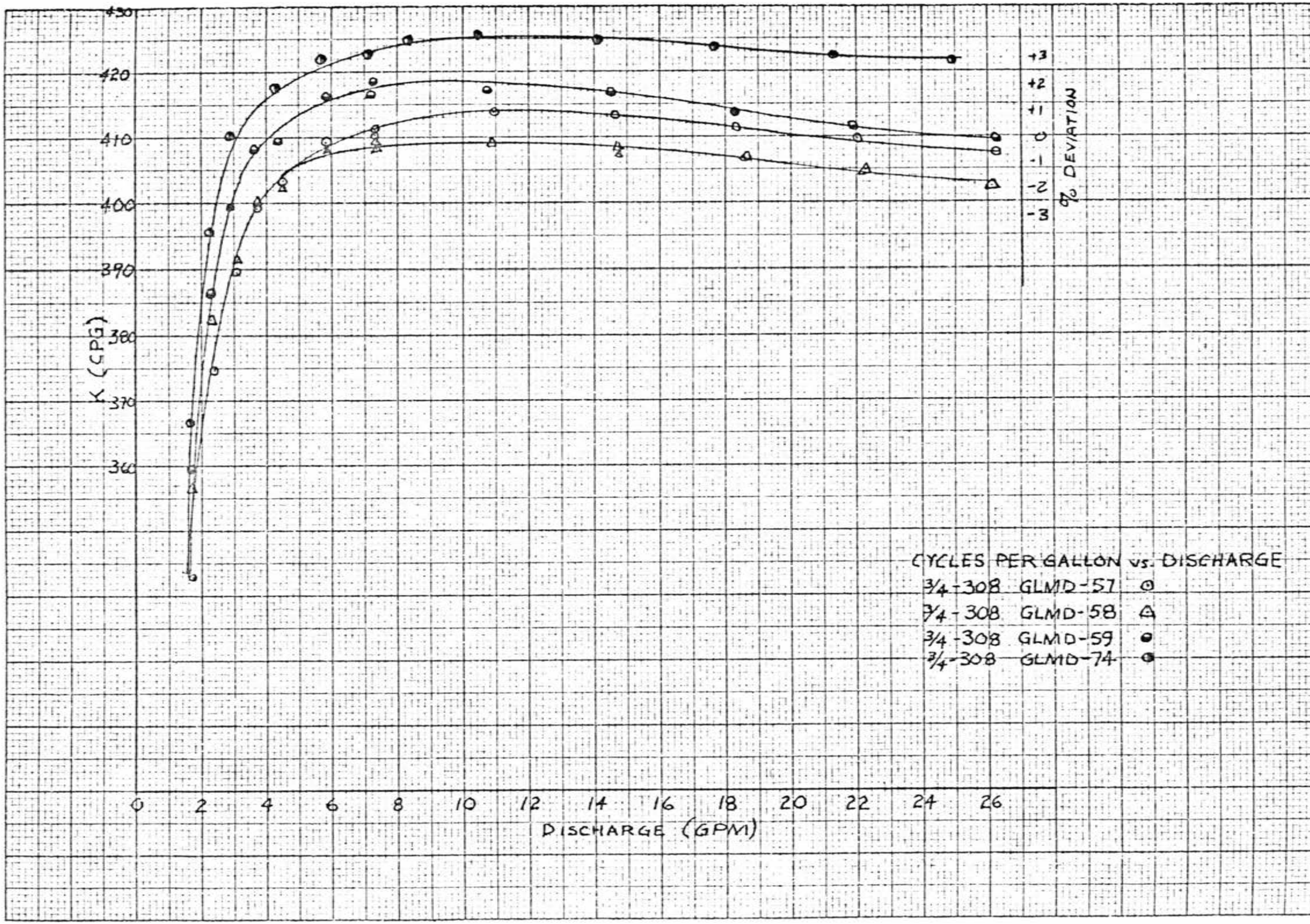
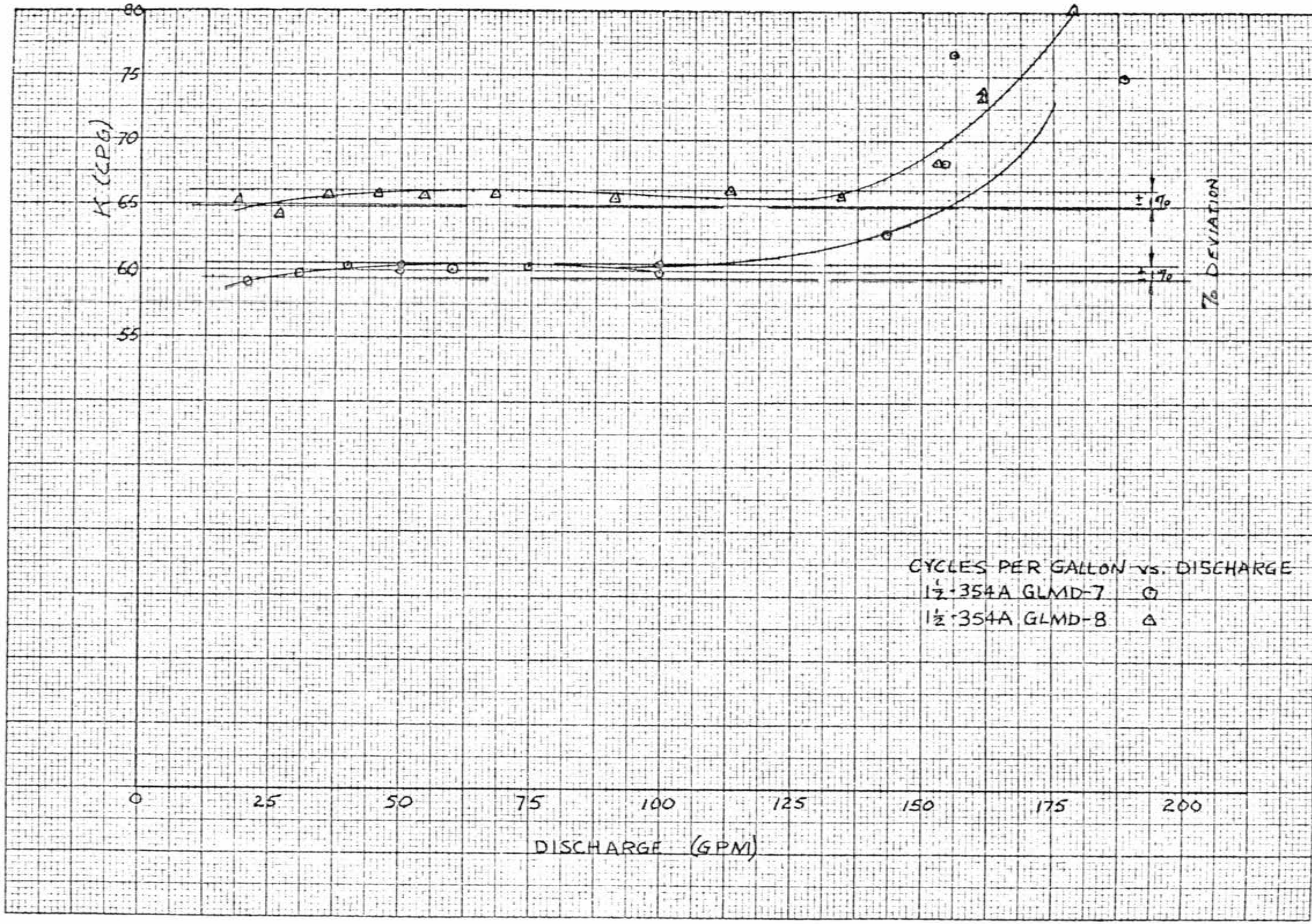
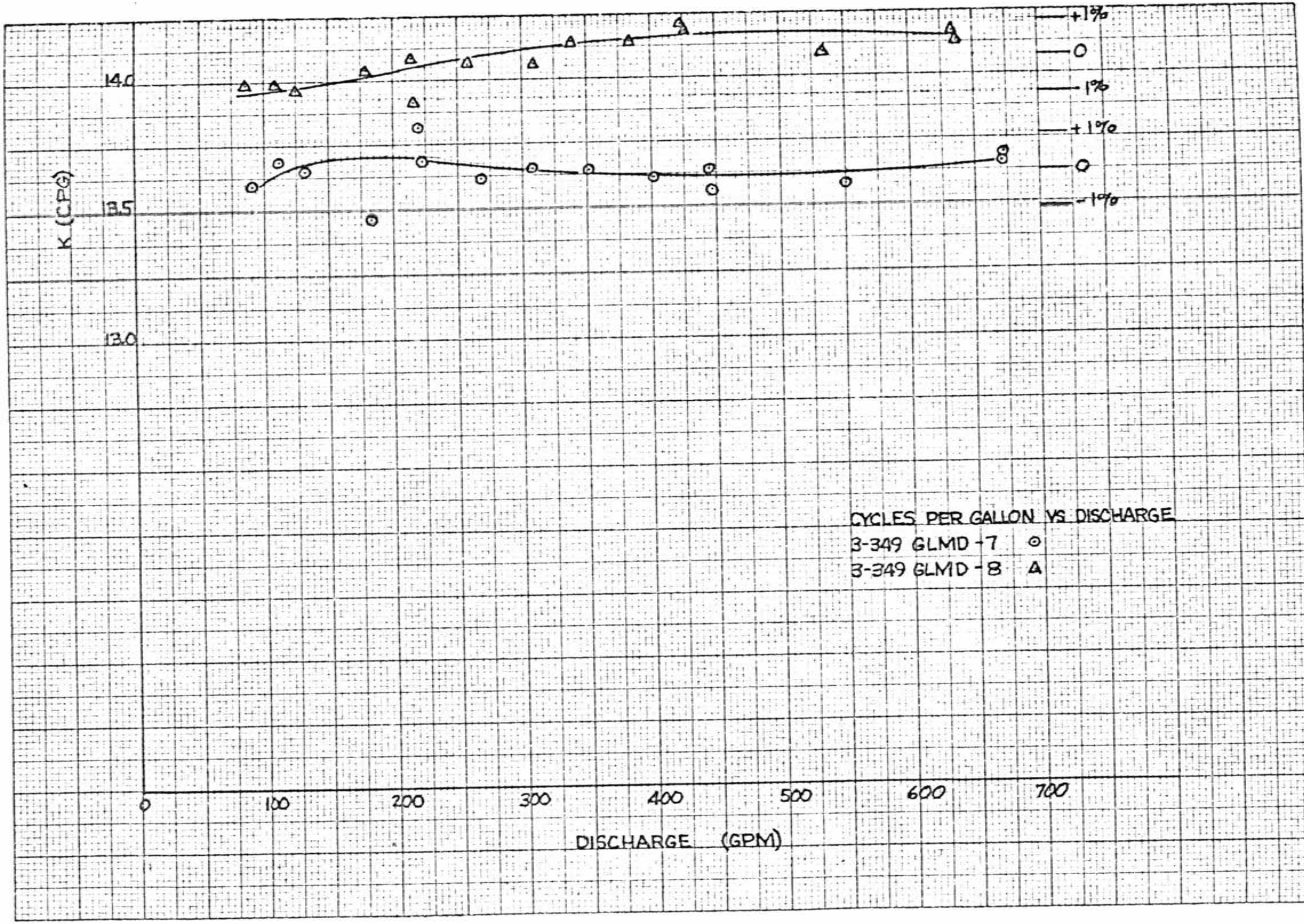

K (CPG)
430
420
410
400
390
380
370
360
% DEVIATION
+3
+2
+1
0
-1
-2
-3
0 2 4 6 8 10 12 14 16 18 20 22 24 26
DISCHARGE (GPM)
CYCLES PER GALLON vs. DISCHARGE
3/4-308 GLMD-57
3/4-308 GLMD-58
3/4-308 GLMD-59
3/4-308 GLMD-74

FIG. 18


K (CPG)
80
75
70
65
60
55
% DEVIATION
± 1%
± 1%
CYCLES PER GALLON vs. DISCHARGE
1½-354A GLMD-7 ⊙
1½-354A GLMD-8 △
0
25
50
75
100
125
150
175
200
DISCHARGE (GPM)
FIG. 19

K (CPG)
60
55
50
45
+10%
+5%
0
-5%
-10%
0
100
200
300
400
DISCHARGE (GPM)
CYCLES PER GALLON VS DISCHARGE
2-353 GLMD-2 ⊙
2-353 GLMD-41 △

FIG. 20



+1%
0
-1%
+1%
0
-1%
14.0
13.5
13.0
K (CPG)
0
100
200
300
400
500
600
700
DISCHARGE (GPM)
CYCLES PER GALLON VS DISCHARGE
3-349 GLMD -7 ⊙
3-349 GLMD -8 Δ

Fig. 21

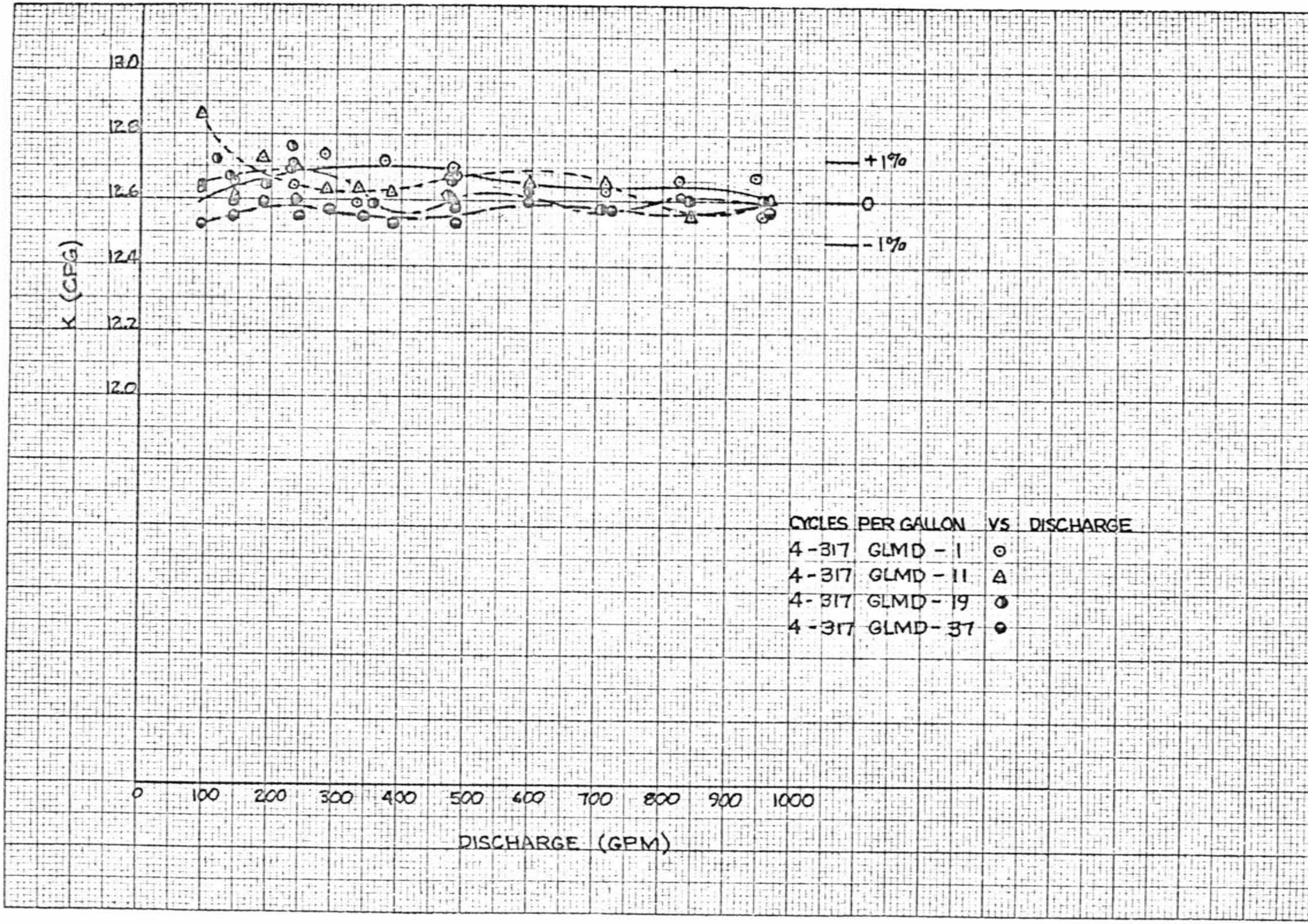

K (CPG)
13.0
12.8
12.6
12.4
12.2
12.0
+1%
0
-1%
0
100
200
300
400
500
600
700
800
900
1000
DISCHARGE (GPM)
CYCLES PER GALLON VS DISCHARGE
4-317 GLMD-1
4-317 GLMD-11
4-317 GLMD-19
4-317 GLMD-37

FIG. 22

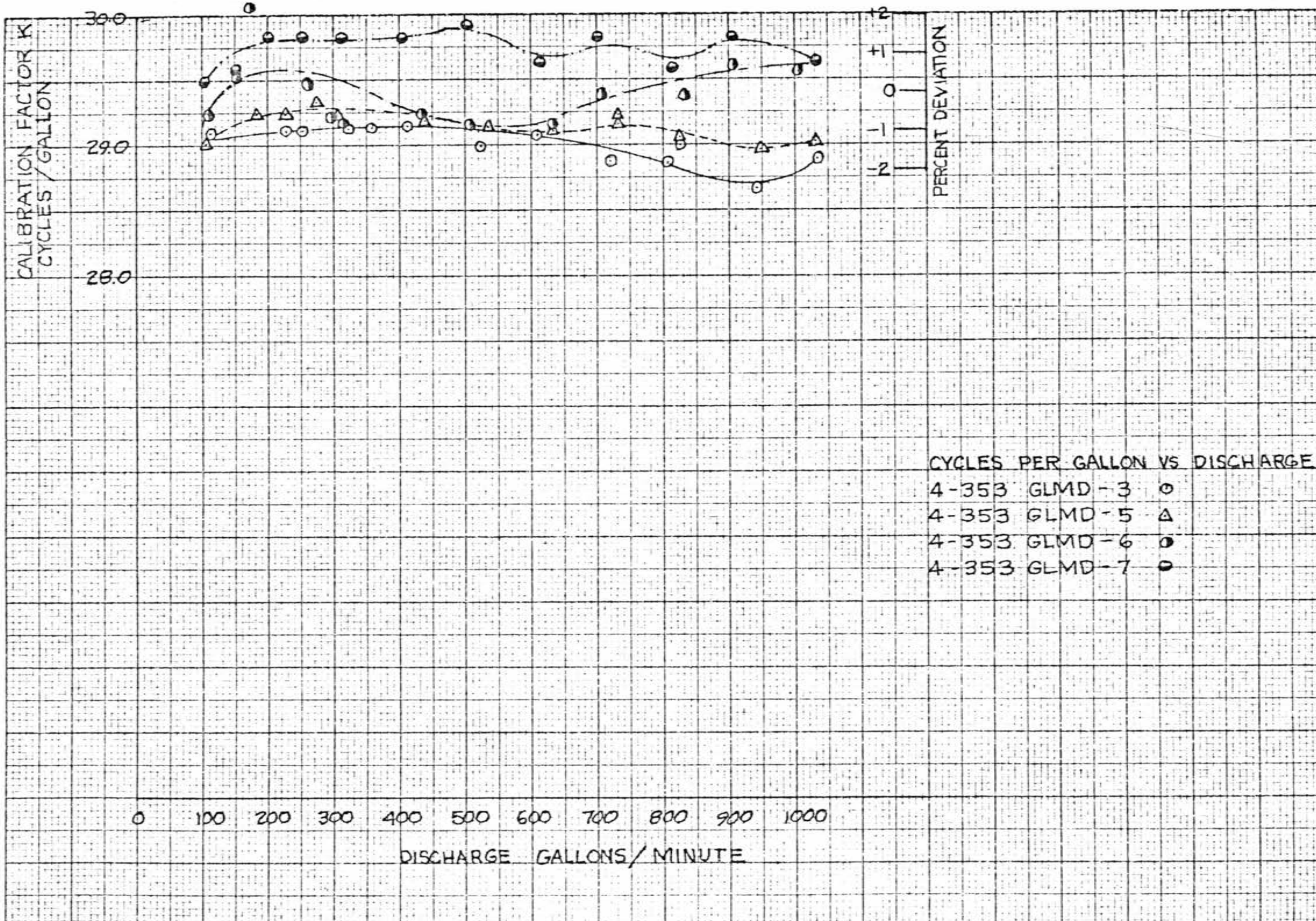

CALIBRATION FACTOR K
CYCLES / GALLON
30.0
29.0
28.0
PERCENT DEVIATION
+2
+1
0
-1
-2
0
100
200
300
400
500
600
700
800
900
1000
DISCHARGE GALLONS/ MINUTE
CYCLES PER GALLON VS DISCHARGE
4-353 GLMD-3
4-353 GLMD-5
4-353 GLMD-6
4-353 GLMD-7

FIG. 23

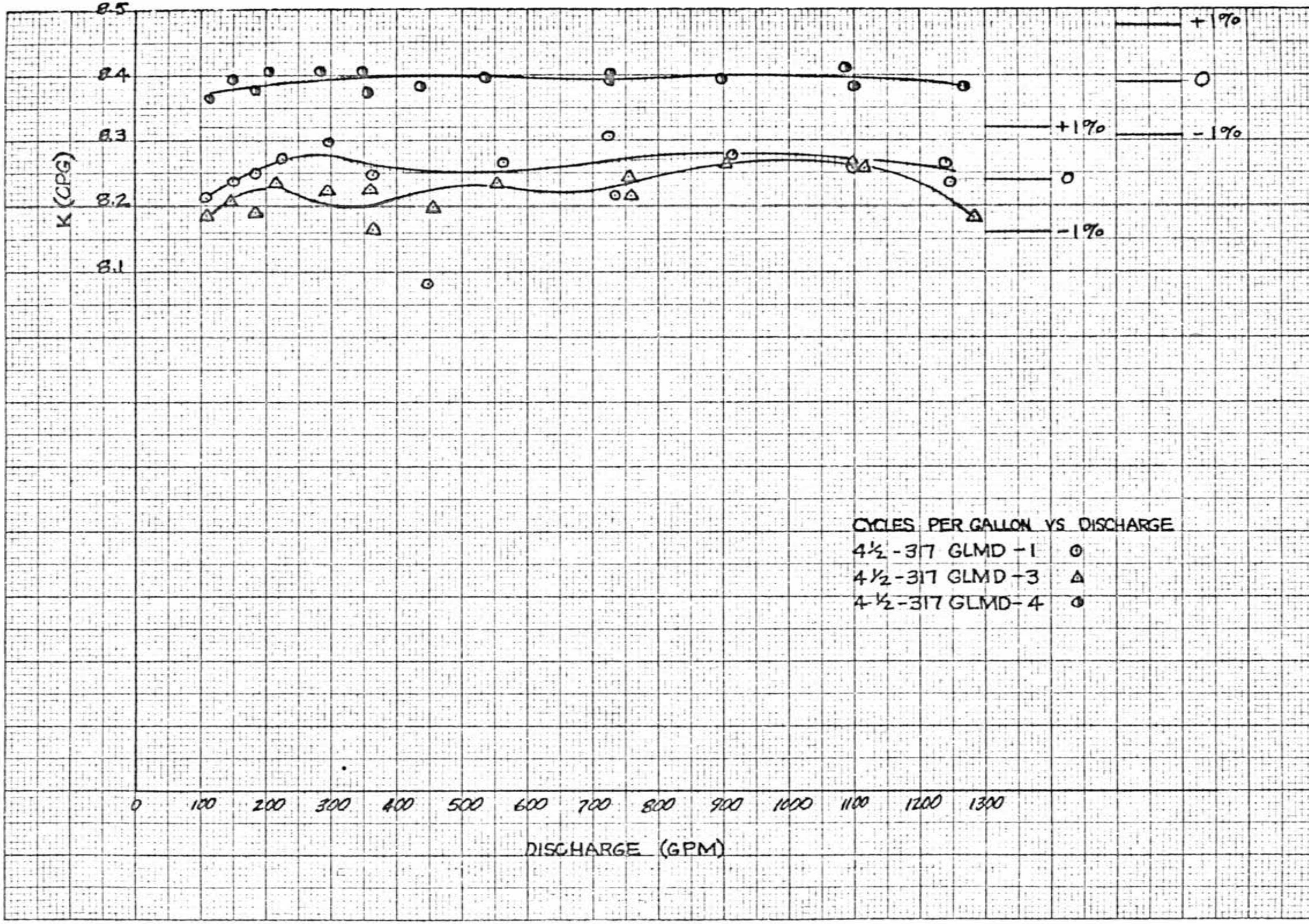
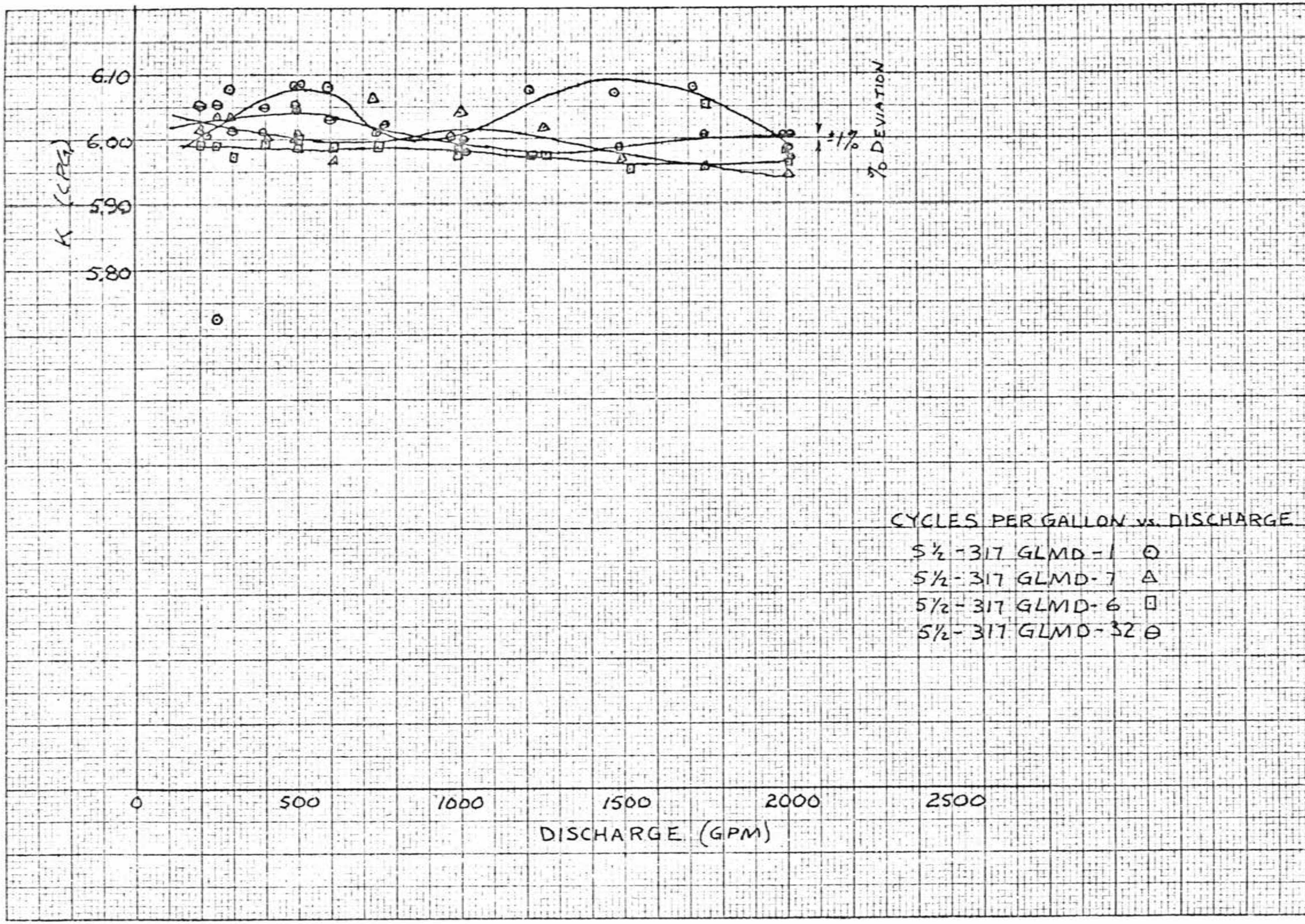
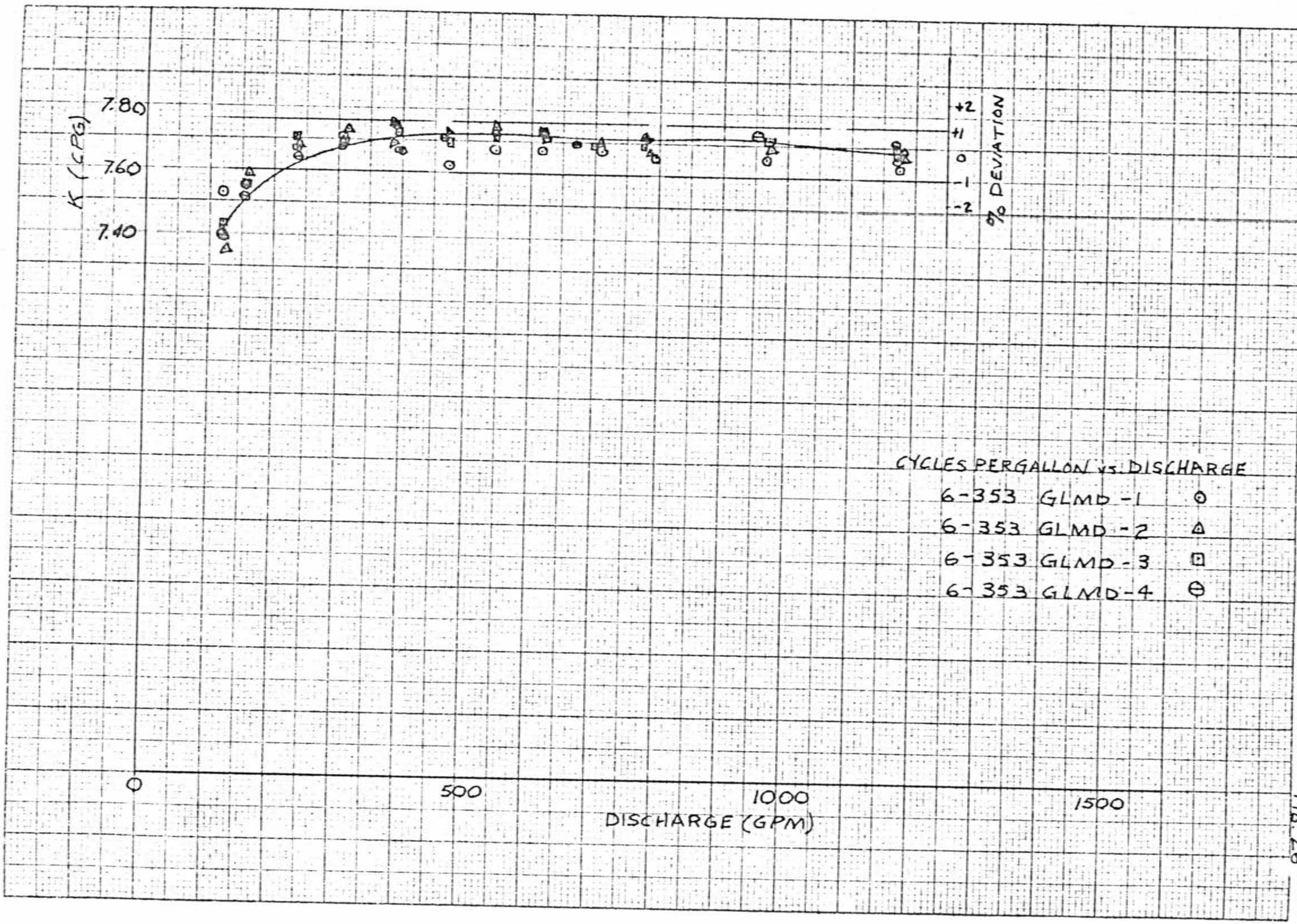

8.5
8.4
8.3
8.2
8.1
K (CPG)
+1%
0
-1%
+1%
0
-1%
CYCLES PER GALLON VS DISCHARGE
4½-317 GLMD-1
4½-317 GLMD-3
4-½-317 GLMD-4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
DISCHARGE (GPM)

FIG. 24



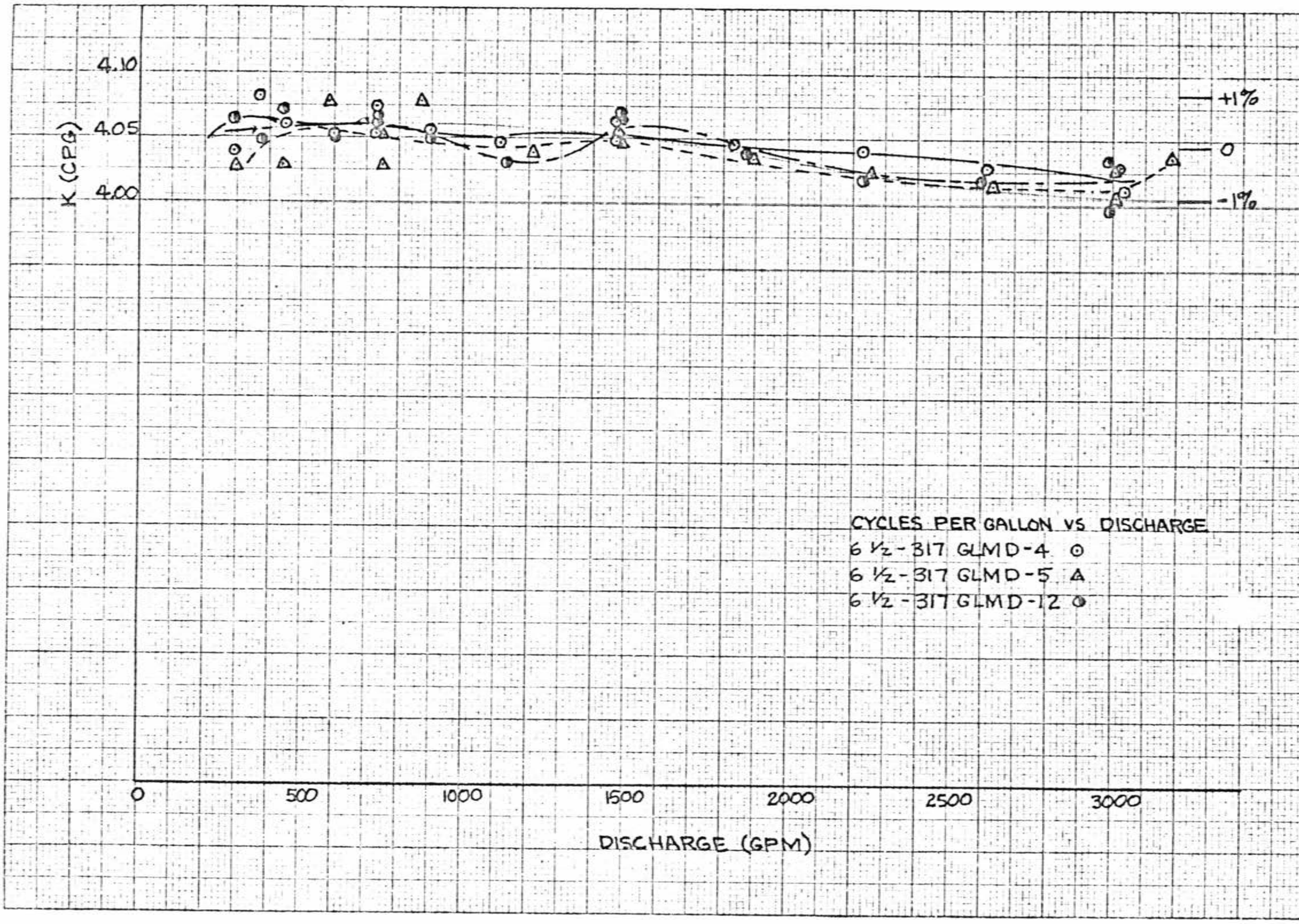
6.10
6.00
5.90
5.80
K (CPG)
±1%
% DEVIATION
0
500
1000
1500
2000
2500
DISCHARGE (GPM)
CYCLES PER GALLON vs. DISCHARGE
5½-317 GLMD-1 ⊙
5½-317 GLMD-7 △
5½-317 GLMD-6 ⊡
5½-317 GLMD-32 ⊖

FIG. 25



K (CPG)
7.80
7.60
7.40
+2
+1
0
-1
-2
% DEVIATION
CYCLES PERGALLON vs DISCHARGE
6-353 GLMD-1
6-353 GLMD-2
6-353 GLMD-3
6-353 GLMD-4
0
500
1000
1500
DISCHARGE (GPM)

Fig. 26



4.10
4.05
4.00
K (CPG)
+1%
0
-1%
0
500
1000
1500
2000
2500
3000
DISCHARGE (GPM)
CYCLES PER GALLON VS DISCHARGE
6 1/2 - 317 GLMD-4
6 1/2 - 317 GLMD-5
6 1/2 - 317 GLMD-12

FIG. 27

APPENDIX B

FISCHER AND PORTER FLOWMETERS

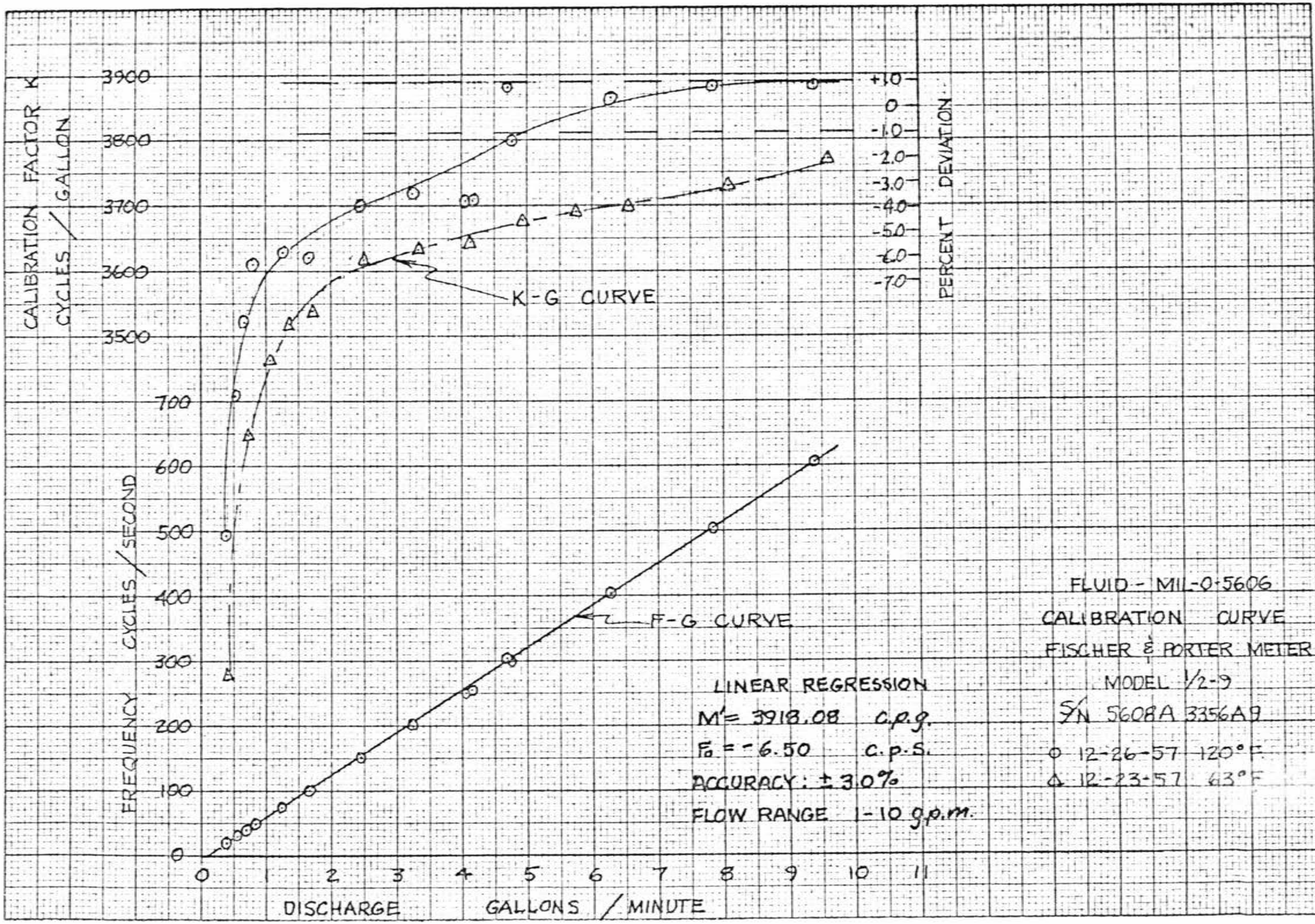

CALIBRATION FACTOR K
CYCLES / GALLON
3900
3800
3700
3600
3500
+1.0
0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
PERCENT DEVIATION
K-G CURVE
FREQUENCY CYCLES / SECOND
700
600
500
400
300
200
100
0
F-G CURVE
0 1 2 3 4 5 6 7 8 9 10 11
DISCHARGE GALLONS / MINUTE
LINEAR REGRESSION
M' = 3918.08 c.p.g.
Fo = -6.50 c.p.s.
ACCURACY: ± 3.0%
FLOW RANGE 1-10 g.p.m.
FLUID - MIL-O-5606
CALIBRATION CURVE
FISCHER & PORTER METER
MODEL 1/2-9
S/N 5608A 3356A9
○ 12-26-57 120°F
△ 12-23-57 63°F

FIG. 28

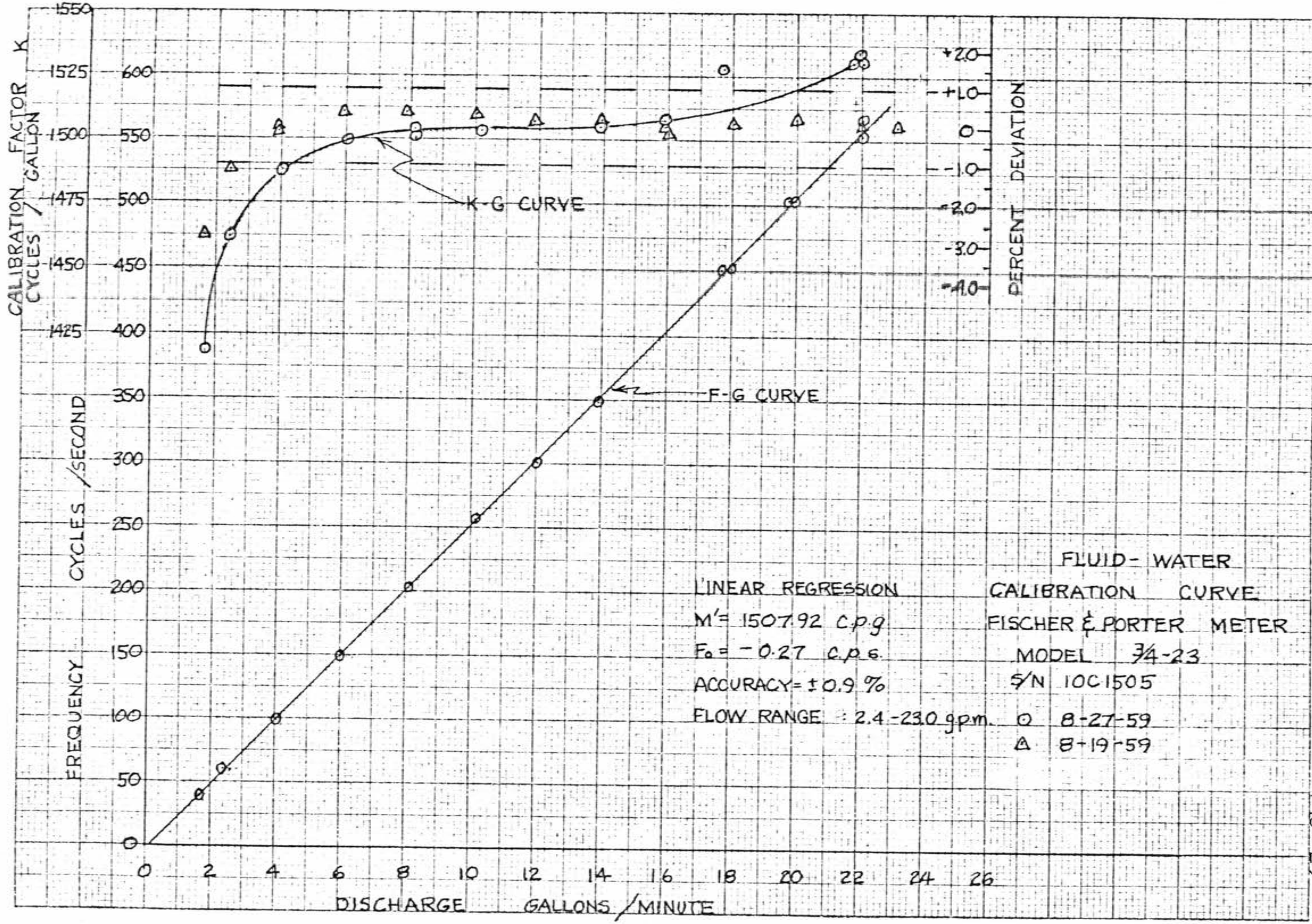

CALIBRATION FACTOR K
CYCLES / GALLON
1550
1525
1500
1475
1450
1425
600
550
500
450
400
350
300
250
200
150
100
50
0
+2.0
+1.0
0
-1.0
-2.0
-3.0
-4.0
PERCENT DEVIATION
K-G CURVE
F-G CURVE
FREQUENCY CYCLES /SECOND
0 2 4 6 8 10 12 14 16 18 20 22 24 26
DISCHARGE GALLONS /MINUTE
LINEAR REGRESSION
M'= 1507.92 c.p.g
F₀ = -0.27 c.p.s.
ACCURACY= ±0.9 %
FLOW RANGE : 2.4-23.0 gpm.
FLUID- WATER
CALIBRATION CURVE
FISCHER & PORTER METER
MODEL 3/4-23
S/N 10C1505
○ 8-27-59
△ 8-19-59

FIG. 29

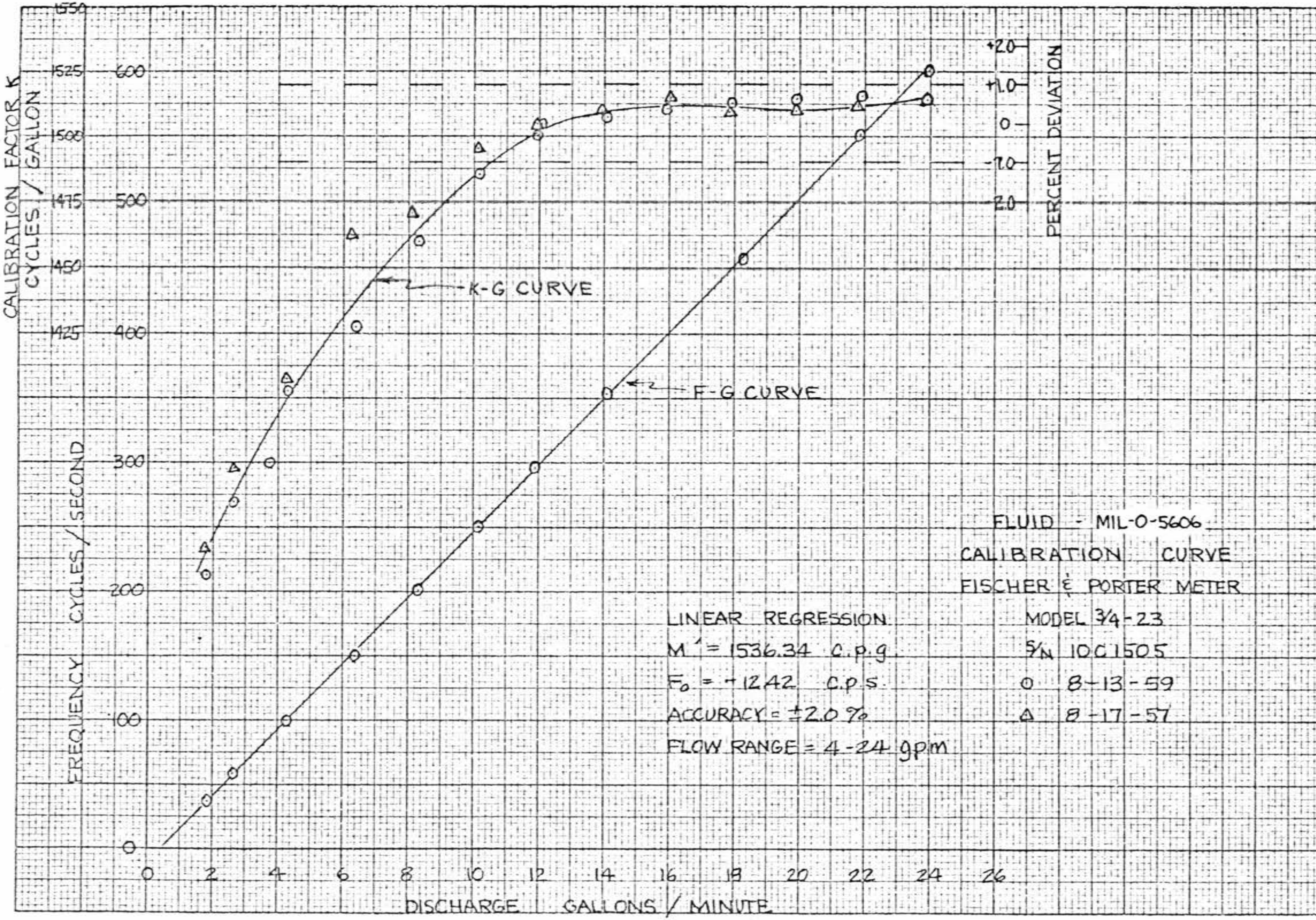

CALIBRATION FACTOR K CYCLES / GALLON
FREQUENCY CYCLES / SECOND
PERCENT DEVIATION
DISCHARGE GALLONS / MINUTE
K-G CURVE
F-G CURVE
FLUID - MIL-O-5606
CALIBRATION CURVE
FISCHER & PORTER METER
MODEL 3/4-23
S/N 10C1505
○ 8-13-59
△ 8-17-57
LINEAR REGRESSION
M' = 1536.34 c.p.g
F₀ = +12.42 c.p.s.
ACCURACY = ±2.0 %
FLOW RANGE = 4-24 gpm

FIG. 30

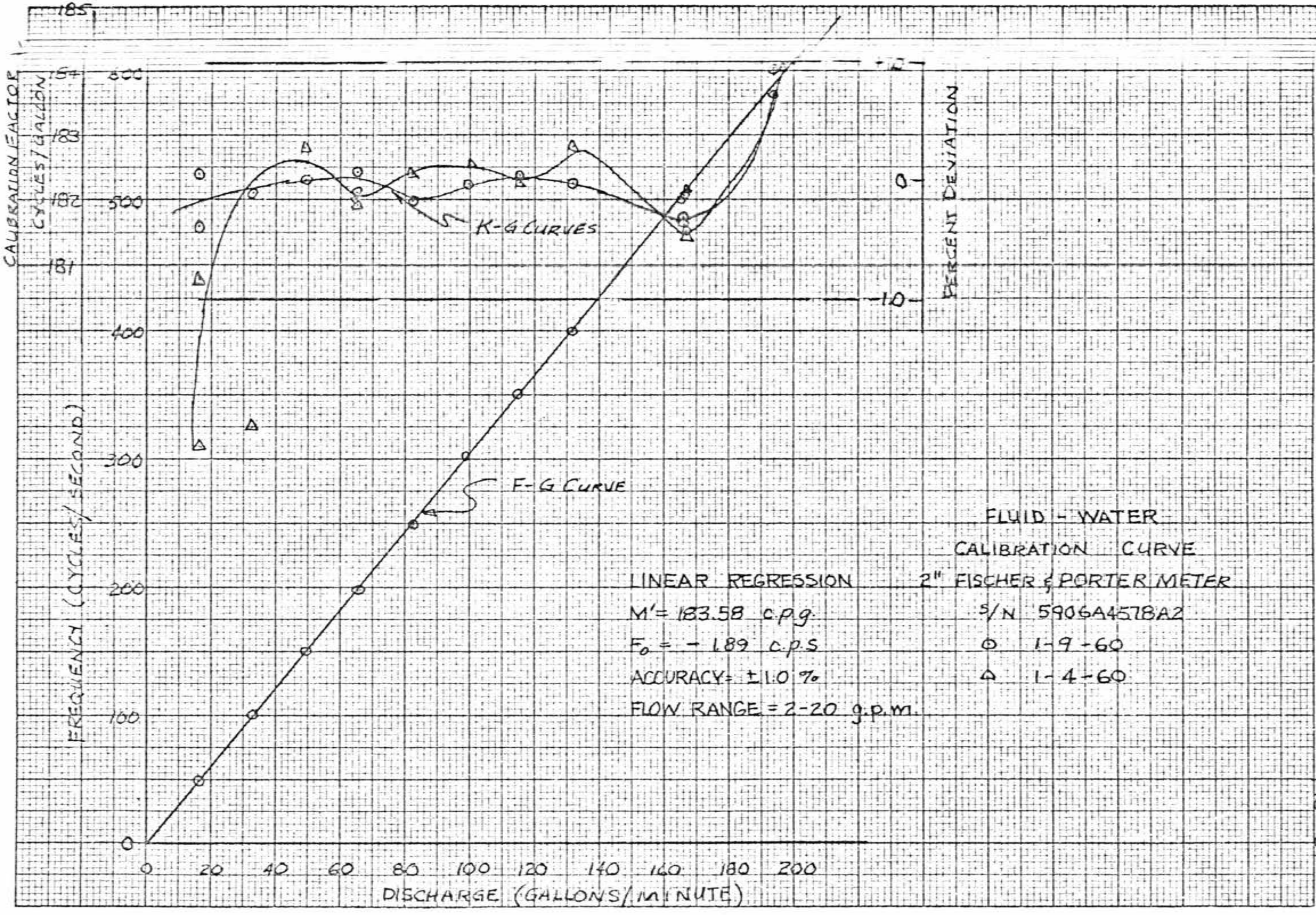

CALIBRATION FACTOR CYCLES/GALLON
185
184
183
182
181
800
500
400
300
200
100
0
+10
0
-10
PERCENT DEVIATION
K-G CURVES
F-G CURVE
FREQUENCY (CYCLES/SECOND)
0 20 40 60 80 100 120 140 160 180 200
DISCHARGE (GALLONS/MINUTE)
FLUID - WATER
CALIBRATION CURVE
2" FISCHER & PORTER METER
S/N 5906A4578A2
⊙ 1-9-60
△ 1-4-60
LINEAR REGRESSION
M' = 183.58 c.p.g.
F0 = - 1.89 c.p.s
ACCURACY = ±1.0 %
FLOW RANGE = 2-20 g.p.m.

FIG. 31

APPENDIX C

WAUGH FLOWMETERS

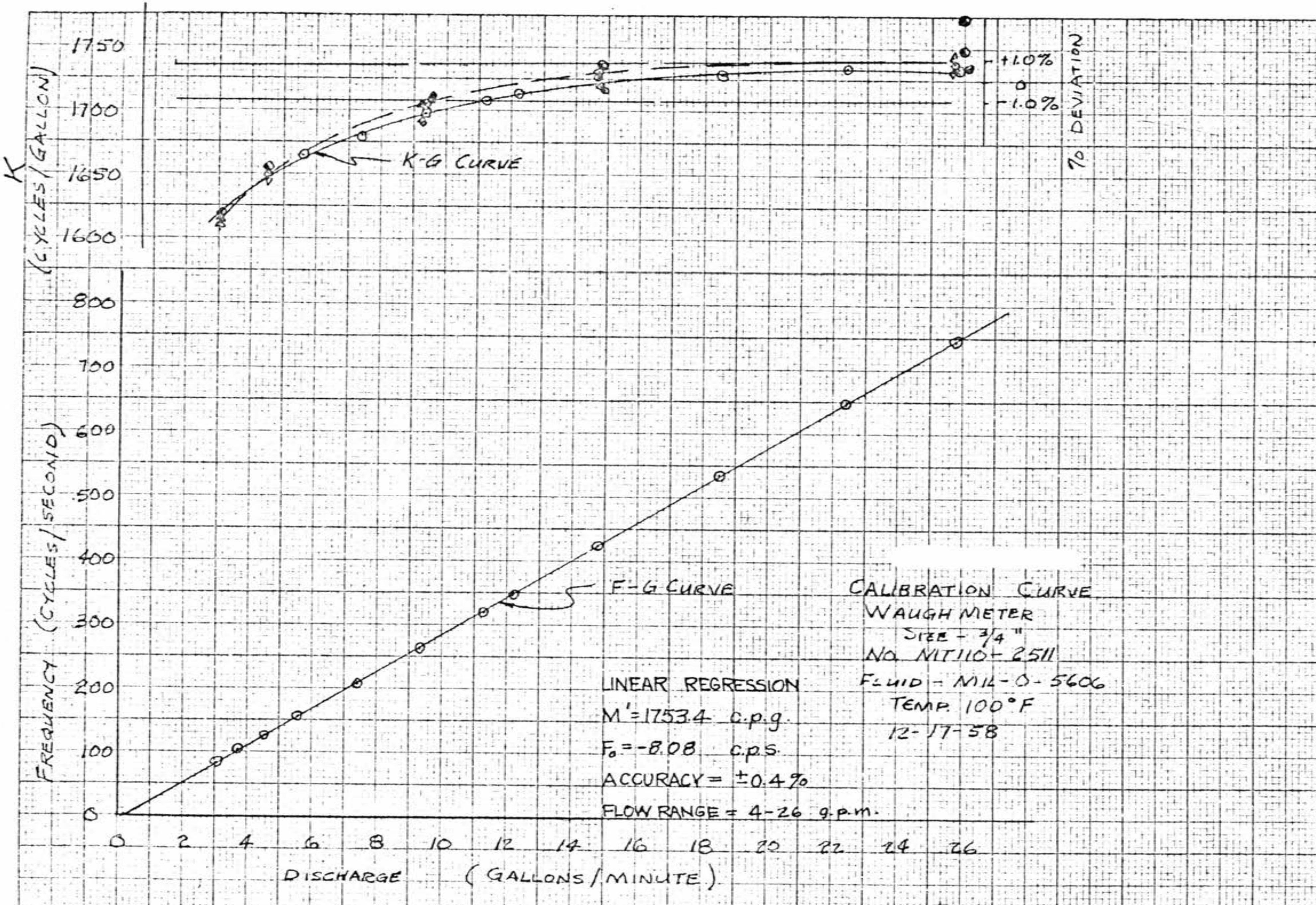

1750
1700
1650
1600
K (CYCLES / GALLON)
+1.0%
0
-1.0%
% DEVIATION
K-G CURVE
800
700
600
500
400
300
200
100
0
FREQUENCY (CYCLES / SECOND)
F-G CURVE
CALIBRATION CURVE
WAUGH METER
SIZE - 3/4"
No. MT110-2511
FLUID - MIL-O-5606
TEMP. 100°F
12-17-58
LINEAR REGRESSION
M' = 1753.4 c.p.g.
F₀ = -8.08 c.p.s.
ACCURACY = ±0.4%
FLOW RANGE = 4-26 g.p.m.
0 2 4 6 8 10 12 14 16 18 20 22 24 26
DISCHARGE (GALLONS / MINUTE)

FIG. 32

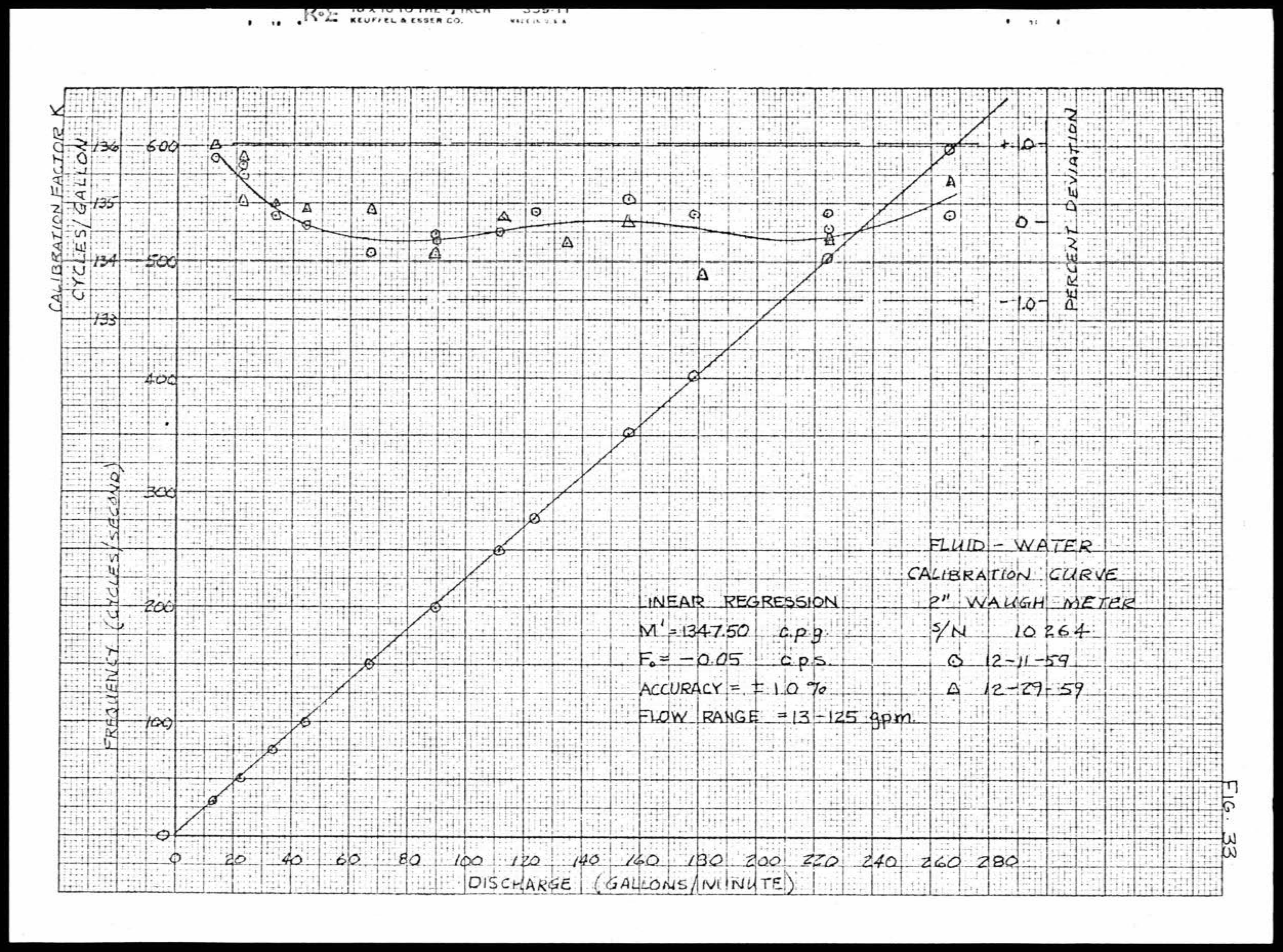

K&E 10 X 10 TO THE ½ INCH 359-11
KEUFFEL & ESSER CO.
CALIBRATION FACTOR K
CYCLES/GALLON
136
135
134
133
600
500
400
300
200
100
0
+1.0
0
-1.0
PERCENT DEVIATION
FREQUENCY (CYCLES/SECOND)
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280
DISCHARGE (GALLONS/MINUTE)
FLUID - WATER
CALIBRATION CURVE
2" WAUGH METER
S/N 10264
⊙ 12-11-59
△ 12-29-59
LINEAR REGRESSION
M' = 1347.50 c.p.g.
F₀ = -0.05 c.p.s.
ACCURACY = ± 1.0 %
FLOW RANGE = 13-125 gpm.

FIG. 33