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# *Speed Calibration of the Plessey Model M021 Self-Recording Current Meter*

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# *Acknowledgments*

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## I. INTRODUCTION

The Canada Centre for Inland Waters has been using the Plessey Model M021 self-recording current meter since 1967. Because of the low speeds generally measured with this meter, it became desirable to look closely at the speed calibration in the range of about 0 to 100 cm/sec., and especially that in the range 0 to 15 cm/sec.

Very little direct calibration data exists for the speed sensor. The Plessey Company supplies a standard (first order) calibration equation, and meters are considered acceptable if their speeds fall within ±1 cm/sec. of this standard curve. The author arranged to have one current meter speed sensor calibrated by the National Research Council of Canada (N.R.C., 1967), and a set of calibrations was carried out on a meter used in the intercomparison tests at WHOI mooring site "D" (UNESCO, 1970). These few calibration tests were, however, unsatisfactory, since the statistical sample of carefully controlled calibrations was still small.

It was for this reason that the decision was made to run a larger set of static speed calibration tests under carefully controlled conditions, in order to ascertain a "best" calibration, as well as provide an idea of the variability to be expected. In addition, a few tests of the behaviour of the speed sensor under conditions of tilt of the instrument were done to ascertain the sensitivity of the sensor to deviation from the normal horizontally suspended position. These calibrations were run at Calgary by Mr. N. De Zeeuw (see Section III for description of the calibration facility).

## II. DESCRIPTION OF THE PLESSEY MODEL M021 CURRENT METER

A detailed description of the meter is given in the manual supplied by the manufacturer (Plessey, 1967); in addition, a more general description is given by Hodges (1967).

The features of this meter which have relevance to the speed calibration, are the sensor-pickup-integrator system, and the meter suspension itself.

The speed sensor is a rotor suspended horizontally by water-lubricated bearings; the rate of rotation of the rotor is integrated over time using a magnetic follower coupled to the rotor, with the follower turning a reduction gear train (normally 10,500:1) attached to a 360° potentiometer. The integrated value of the rotor rotation rate, thus shows up as a change in resistance over time; this is measured by means of a bridge circuit in the meter. The major frictional losses on the sensor occur at the suspension bearings (water lubricated) of the rotor, as well as the magnetically coupled gear train - potentiometer system. Because no two sets of bearings, or gear trains have exactly the same characteristics, some differences in calibration among different meters should thus be expected.

The meter itself is suspended from an inverted U yoke, which is attached to a vertical swivel to allow the meter to turn through 360°. The meter itself is free to rotate in the vertical plane by the suspension pins attaching the meter to the inverted U yoke. The meter is designed to stay horizontal when the whole meter has been submerged, but here also, because of some variability in positions of points of suspension, the meters may not hang horizontally, and some statistical error in the calibrations could arise. The sensor itself, because of symmetry about the horizontal axis, should behave with a cosine response.

## III. DESCRIPTION OF THE CALIBRATION FACILITY

The current meters were calibrated at the "Current Meter Rating and Experimental Station" at Calgary, Alberta. This station, established in 1911, is used by the Water Survey of Canada to rate current meters employed in stream measuring programs throughout Canada.

The rating tank is 300 feet long, 5½ feet deep and 6 feet wide, and is fitted with vertical baffles to minimize surging. A towing carriage sits over the tank, and can move along the tank's length on a set of steel rails which straddle the tank. The carriage itself is self-propelled, being driven by a 10 hp., constant-speed electric motor which obtains its power via a 3-wire trolley line. A hydraulic variable speed gear enables the carriage to move with speeds in the range of about 0.05 to 15.0 ft/sec. (1.5 - 457 cm/sec.).

The speed of the carriage is determined by accurately measuring the time taken to travel a fixed distance. The distance is measured by a photo-cell device on the carriage, which is used to step a relay each time the carriage passes an interrupter attached at five-foot intervals along the side of the tank. A timer is started when the carriage passes an interrupter, and stops when a set number of interrupters have been passed. The distance (no. of interruptions x 5 feet) and time are thus measured simultaneously.

The meter to be rated or calibrated is hung under the carriage, and signals, denoting the rate of rotation of the speed sensor, are counted.

## IV. METHOD OF CALIBRATION

Each meter to be calibrated was suspended under the towing carriage in such a fashion that the meter, including the tail fin, was wholly submerged. The attitude of the meter, that is, the angle that the long axis of the meter made with the horizontal, was fixed by attaching the tail fin firmly to the carriage. In this way, the attitude could be varied, and any yawing motion prevented.

Twenty towing runs were made with each meter, two at each of 10 different speeds. These two consist of one run in each direction, to minimize effects of water movement in the towing tank. The calibration for low speeds consisted of counting revolutions per minute for a fixed length run of 50 feet, with the time between the 50-foot markers being measured with a timer. The revolutions were measured by visually counting the turns, using a white identifying mark on one blade of the rotor. For higher speeds, a movie camera was used to record the propellor rotation and an electric timer with an expanded scale.

To measure the effect of attitude, the tail fin was raised to obtain the desired angle between the axis of the meter and the horizontal. The angle to the horizontal used, beside 0 degrees, was 30 degrees. In addition, meters which had been modified with a back plate clamped to the meter case, were also calibrated in the attitude they normally hung in water; that is, with tail slightly down. Many meters with this modification had not been properly balanced subsequent to the modification, and a check was made to note the effect of this slight lack of balance.

## V. CALIBRATION RESULTS

### (a) Calibration of Balanced, Horizontal Meters

Most care was expended in carrying out this calibration in the range 3 - 15 cm/sec., since this was the range where the majority of measured values occurred. The calibration results are shown in Figure 1: the "standard" calibration equation supplied by the manufacturer was included for comparison purposes (see Plessey, 1967; Section 4.1 (2)). The variable "N" was the BOD numerical equivalent, derived from values recorded by the meter, of the integrated speed value over 10 minutes.

From Figure 1, it can be seen that the present calibration results agree quite well with the manufacturer's calibration curve; although the calibration points fall a bit above the Plessey calibration curve, giving a difference of about 1.1 cm/sec. at the low end and about 0.3 cm/sec. at the high end of the range. This gives one confidence in the calibrations themselves. Most of the scatter in the results at speeds less than about 10 cm/sec., can be attributed to the errors encountered in using the towing carriage at low speeds; it was not easy to ensure complete uniformity of travel. However, no apparent non-linear trend is visible even at the lowest speeds encountered; so that a straight line calibration curve could be used. The sole exception was the data from a set of calibrations done in 1967 in the towing tank at the National Research Council of Canada. These calibration points were linear down to about 7 cm/sec., and then dropped rapidly below the linear calibration curve, to a "starting speed" (rotor rps. equal to zero) of 4 cm/sec. However, these results below 7 cm/sec. were ultimately discarded in further analysis, since it appeared that the standard procedure of changing rotor bearings prior to the calibration runs had not been carried out.

The data points were then punched up on computer cards, and a least-squares curve fitted to them. The fit was done over the full speed range, as well as separately over the two ranges 0 - 15, and 15 - 70 cm/sec. Fitting was carried out to a fifth order polynomial, to ascertain whether the calibration curve was linear as appeared in Figures 1 and 2. The results are shown in Table 1.

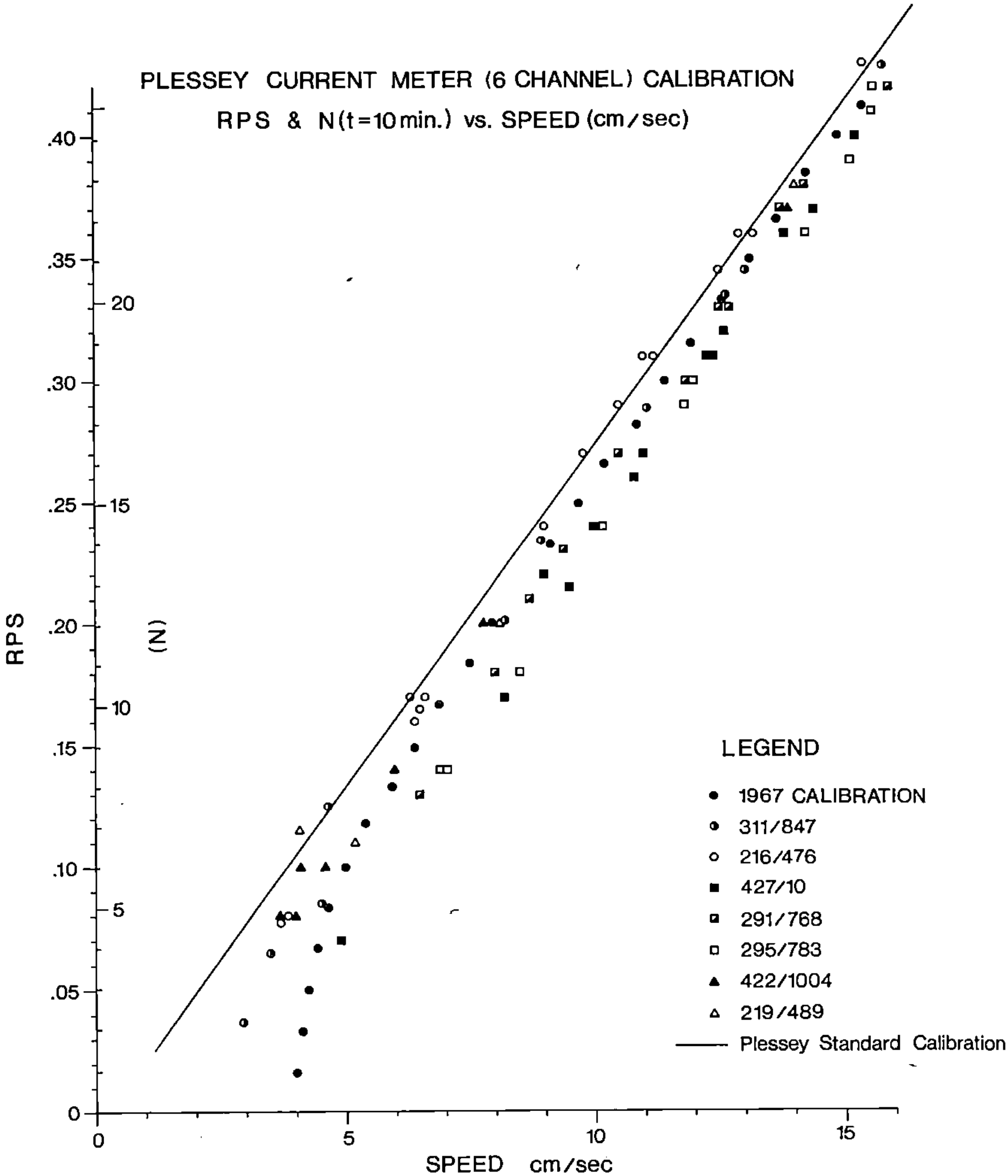

PLESSEY CURRENT METER (6 CHANNEL) CALIBRATION
RPS & N(t=10min.) vs. SPEED (cm/sec)
RPS
(N)
.40
.35
.30
.25
.20
.15
.10
.05
0
20
15
10
5
0
5
10
15
SPEED cm/sec
LEGEND
1967 CALIBRATION
311/847
216/476
427/10
291/768
295/783
422/1004
219/489
Plessey Standard Calibration

Fig.1

PLESSEY CURRENT METER (6 CHANNEL) CALIBRATION

RPS & N(t=10 min.) vs. SPEED (cm/sec)

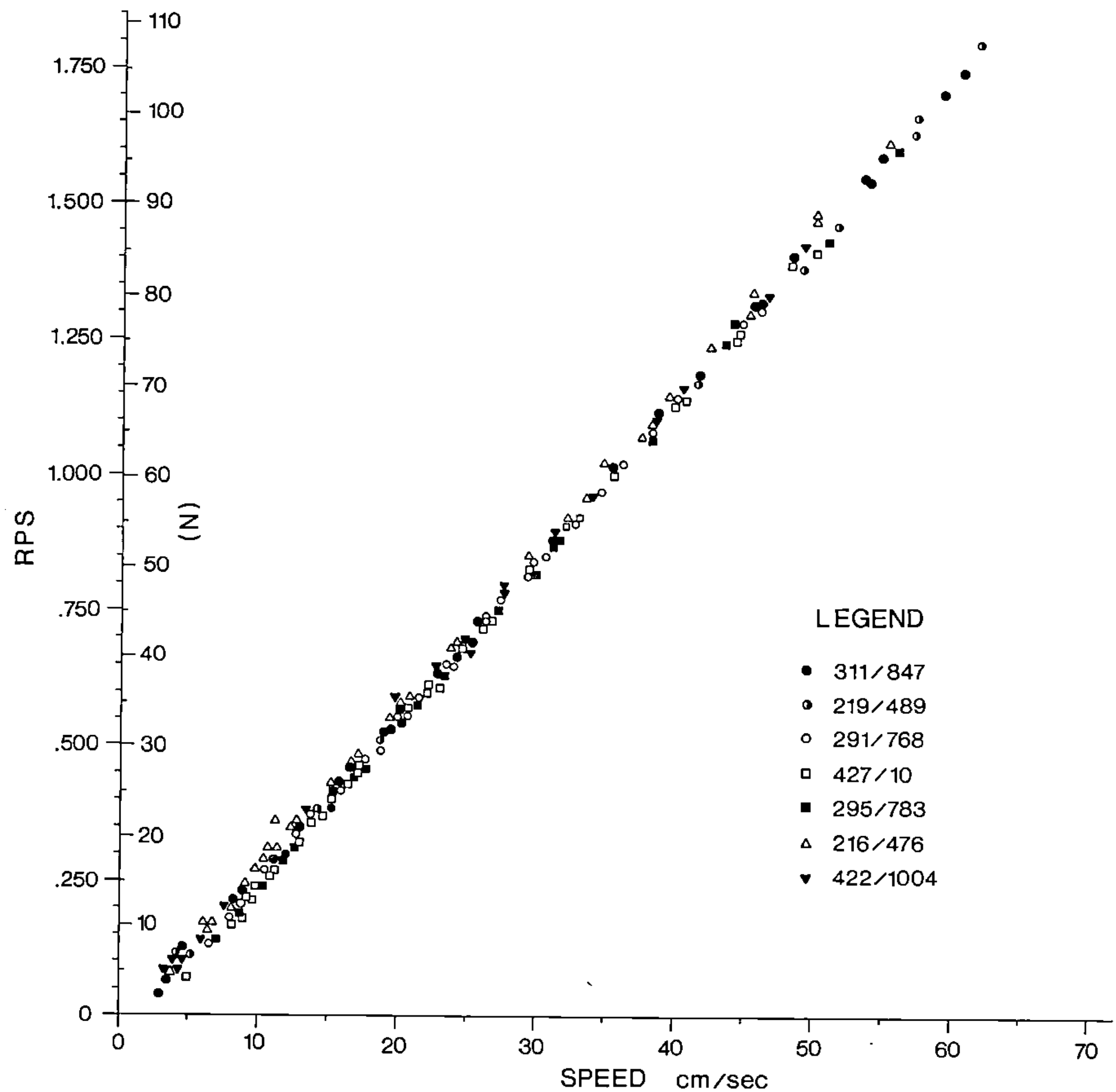



Fig. 2

TABLE 1

Standard Deviation σ of Least-Squares Curve as a Function of Order of Curve

| | | | | | | |
|---|---|---|---|---|---|---|
| A. Range 0 - 70 cm/sec. | | | | | | |
| | Order | 1 | 2 | 3 | 4 | 5 |
| | σ (cm/s) | 0.35 | 0.34 | 0.34 | 0.34 | 0.34 |
| B. Range 0 - 15 cm/sec. | | | | | | |
| | Order | 1 | 2 | 3 | 4 | 5 |
| | σ (cm/s) | 0.27 | 0.26 | 0.26 | 0.26 | 0.26 |
| C. Range 15 - 70 cm/sec. | | | | | | |
| | Order | 1 | 2 | 3 | 4 | 5 |
| | σ (cm/s) | 0.40 | 0.39 | 0.39 | 0.39 | 0.39 |

From Table 1, it is seen that increasing the order from the first order upwards, does not decrease the variance to any statistical significance. Hence, a first-order (straight-line) calibration curve is acceptable; this form of curve was the same as supplied by the manufacturer.

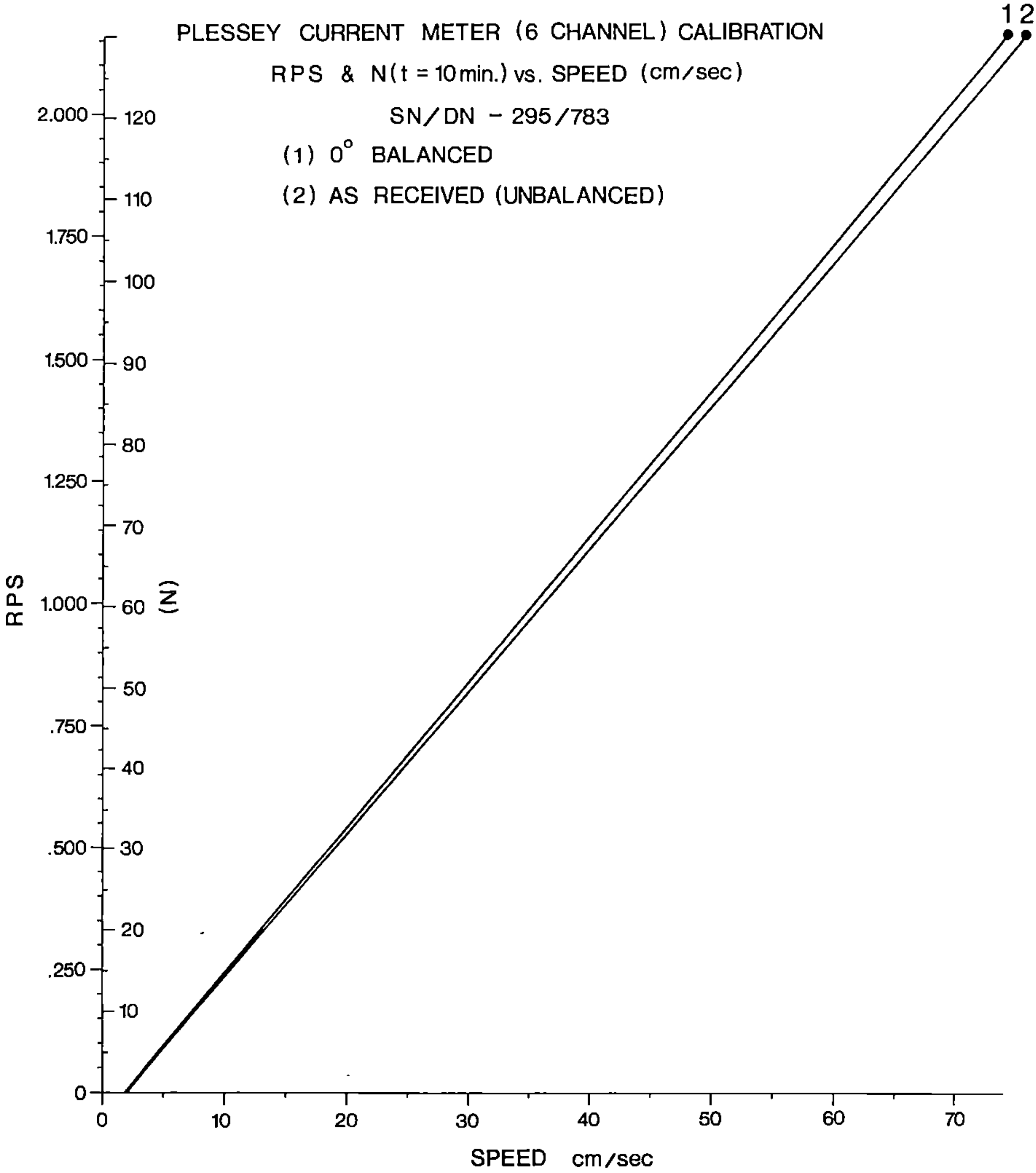
A slight, though non-significant decrease in the variance in the range 0 - 15 cm/sec. is achieved by separately fitting a curve in this range, but the errors of measurement do not lend themselves to arguing unequivocally that a statistically significant improvement in the calibration curve has been made.

The values of the coefficients for the first-order calibration equations, are given in Table 2.

(b) Calibration of Unbalanced Meters

A modification was made to the standard Plessey Model M021 meter to prevent violent expulsion of the end cap of the meter case when the main battery was suddenly shorted and produced large amounts of gas which could blow out the cap. The modification consisted of a pressure relief valve, which would release the internal pressure in the case when the pressure arose above a certain value. In addition, the end cap was held to the case by two U-clamps, similar to the ones holding the front of the meter to the case. These clamps added extra weight at the rear of the case, and some of the meters with this modification would hang "tail down" when submerged in the water.

In order to ascertain the effect this would have on the calibration of the meter, calibrations were run on the same meter, both unbalanced ("tail down"), and subsequently balanced. The results of these calibrations are shown in Figures 3 and 4. It can be seen that the "tail down" meters did not depart very greatly from the standard calibration curve, and did not show any systematic difference (in one case giving higher velocities, and in the other, lower). The larger difference (-4%) is seen in Figure 3; a rough estimate of the angle of the "tail down" mode, showed that one could



PLESSEY CURRENT METER (6 CHANNEL) CALIBRATION
RPS & N(t = 10 min.) vs. SPEED (cm/sec)
SN/DN - 295/783
(1) 0° BALANCED
(2) AS RECEIVED (UNBALANCED)
1 2
RPS
(N)
2.000
1.750
1.500
1.250
1.000
.750
.500
.250
0
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
SPEED cm/sec

Fig. 3

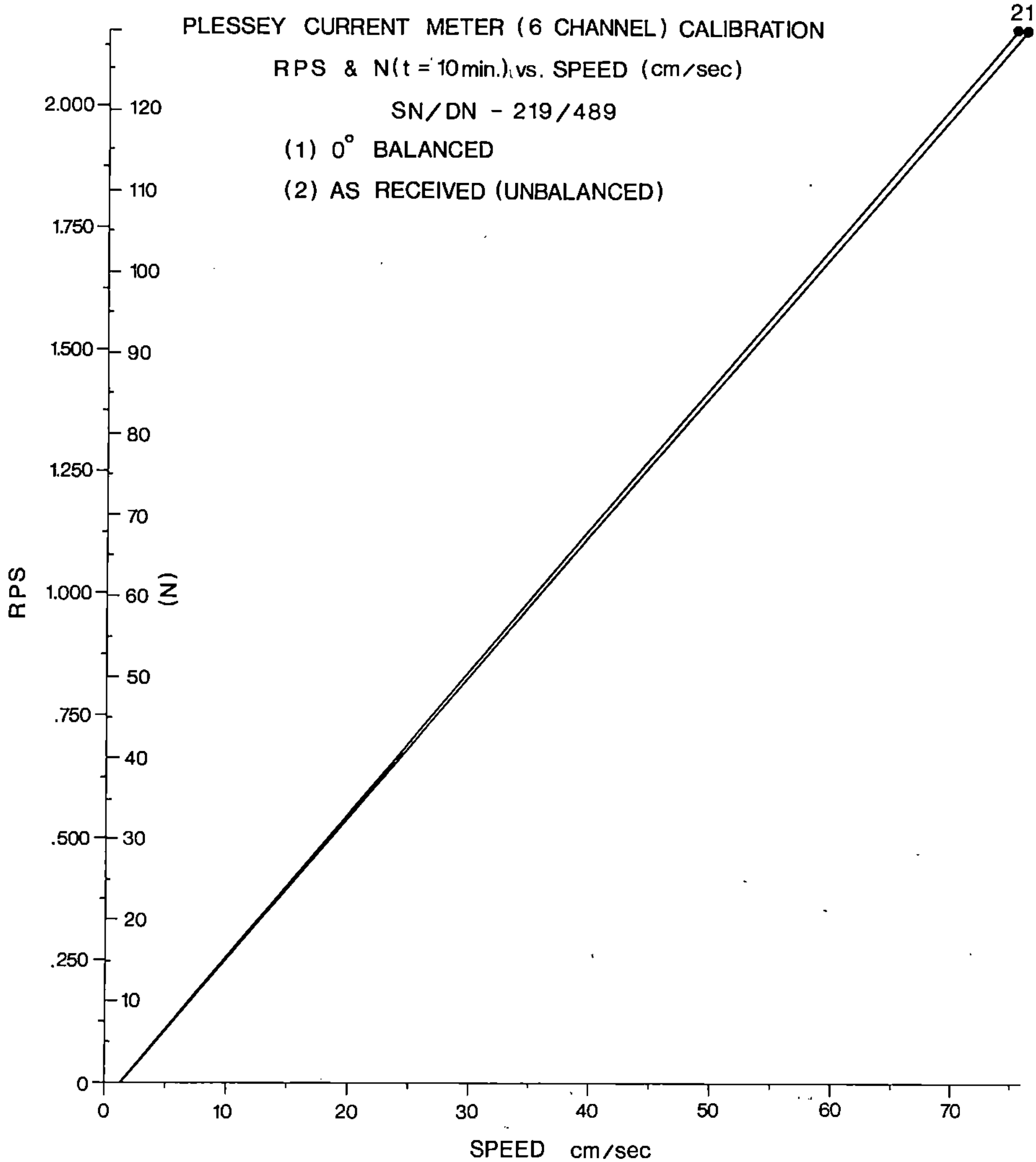

PLESSEY CURRENT METER (6 CHANNEL) CALIBRATION
RPS & N(t = 10 min.) vs. SPEED (cm/sec)
SN/DN - 219/489
(1) 0° BALANCED
(2) AS RECEIVED (UNBALANCED)
21
RPS
(N)
2.000
1.750
1.500
1.250
1.000
.750
.500
.250
0
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
SPEED cm/sec

Fig. 4

TABLE 2

Coefficients for the Linear Calibration Equations

Equations: $U\ (cm/s) = A + BX$

$X = N1 \equiv$ difference between consecutive binary numbers over 10 minute integration period.

$X = N2 \equiv$ rps.

A. Range 0 - 70 cm/sec.

| | A | B | $\sigma$ (cm/s) |
|---|---|---|---|
| N1 | 1.17 | 0.5658 | 0.35 |
| N2 | 1.17 | 34.14 | 0.35 |

B. Range 0 - 15 cm/sec.

| | A | B | $\sigma$ (cm/s) |
|---|---|---|---|
| N1 | 1.38 | 0.5478 | 0.27 |
| N2 | 1.38 | 33.06 | 0.27 |

C. Range 15 - 70 cm/sec.

| | A | B | $\sigma$ (cm/s) |
|---|---|---|---|
| N1 | 1.03 | 0.5678 | 0.40 |
| N2 | 1.03 | 34.27 | 0.40 |

plausibly argue that it followed a cosine response. The smaller difference (Figure 4), was considered to fall within experimental error of the standard (linear) calibration curve. Since the exact angles of "tail down" of the two meters could not be measured with any great amount of precision, the results were considered acceptable from the point of view of using the standard calibration curve for the balanced and unbalanced ("tail down") meters. In future analyses, a slight adjustment in speed downwards, could be made; a value of about -3% would probably be an acceptable correction for all meters which were used in the unbalanced ("tail down") mode.

This unbalanced mode was quickly corrected for all meters, once it was found, and shortly after the pressure modifications were made, all meters had been properly balanced.

### (c) Calibration of a Meter at 0° and 30° to the Horizontal

To provide a rough check as to the behaviour of the speed sensor when the meter was not turned into the flow, one meter was fully calibrated with the horizontal axis of the meter at 0° and 30° to the direction of the flow. This was achieved by tilting the nose of the meter 30° downward during a calibration run.

The results of the 0° and 30° calibration are shown in Figure 5. It can be seen that the impellor is quite directional, and a check of the results shows that within experimental error, the speed sensor exhibits a cosine-law response.

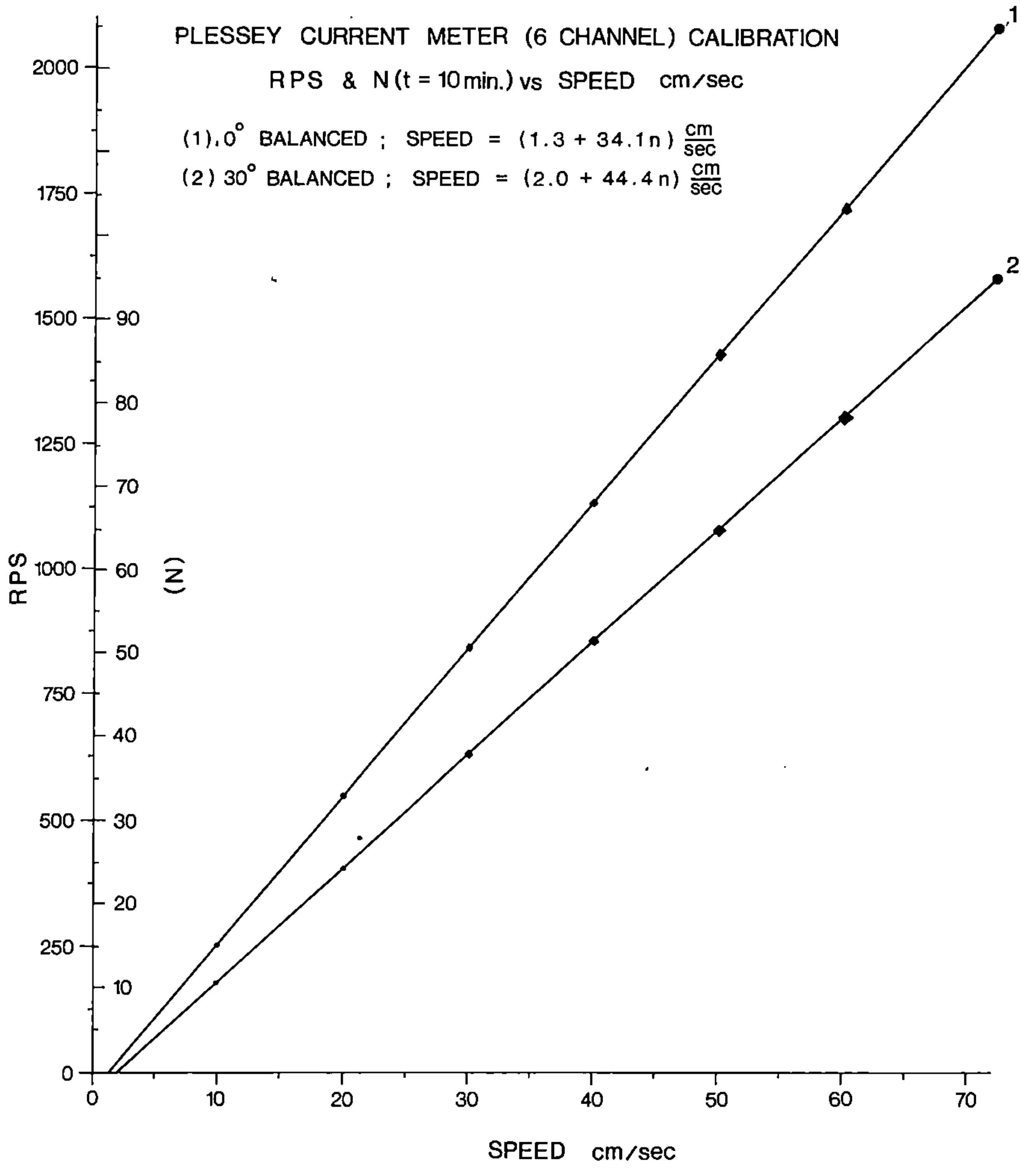

PLESSEY CURRENT METER (6 CHANNEL) CALIBRATION
RPS & N (t = 10 min.) vs SPEED cm/sec
(1) 0° BALANCED ; SPEED = (1.3 + 34.1 n) cm/sec
(2) 30° BALANCED ; SPEED = (2.0 + 44.4 n) cm/sec
RPS
(N)
SPEED cm/sec
1
2

Fig. 5

This response is not unexpected, but further checks on this could profitably be made.

(d) Calibration Tables

A set of calibration tables is provided in Table 3, with calibrations over the full range from 0 - 70 cm/sec. The data are provided in two ways, using the single calibration curve over 0 - 70 cm/sec., and using the segmented curve (0 - 15, 15 - 70 cm/sec.). Differences between the two curves are noted in each case. The standard calibration supplied by the manufacturer, is also included for comparison purposes.

From the table, it can be seen that the differences between the single calibration, and the segmented calibrations (0 - 15, 15 - 70 cm/sec.) is significant up to a speed of about 5 cm/sec. From there on, the differences are small (0.10 cm/sec. or less, 0.6% or less). From consideration of the standard deviations of the least-squares curves, as noted in Table 2, it is seen that it would be more desirable to use the segmented calibration curves, rather than a single curve over the whole range, since the segmented curve has a lower standard deviation (0.27 cm/sec.) in the range 0 - 15 cm/sec., than the single curve over the whole range (=0.35 cm/sec.).

The results in Table 3 are plotted on Figure 6. From the figure and table, it can be seen that, in the range from 0 - 15 cm/sec., the calibration supplied by the manufacturer is too low by amounts ranging from almost 100% to 2%. Thereafter, the differences remain below 5%, and give the best fit between 15 and 30 cm/sec. Since the meter users at C.C.I.W. have used the same servicing procedure as that used by the manufacturer, it is then clear that the manufacturer's calibration is unsuitable for use by these users.

## VI. CONCLUSIONS

Seven Plessey Model M021 current meters were calibrated at the Current Meter Rating and Experimental Station, at Calgary. The calibrations were consistent in giving a straight line (first order) calibration curve, with a standard deviation of 0.3 cm/sec. Higher order calibration curves did not improve the fit; a somewhat lesser variance was achieved by splitting the calibration range of 0 - 70 cm/sec. into two segments: 0 - 15, and 15 - 70 cm/sec.

Balanced and unbalanced (caused by the pressure modifications) meters showed little change in calibration; for the unbalanced meters, the speeds could be lowered by about 3% if one desires higher accuracy.

The speed sensor appears to follow the cosine law response, according to the check made. This could be further confirmed by subsequent calibrations.

A calibration table was generated from the different calibration equations. Intercomparison of the two tables (single curve over the full range, segmented curve over the ranges 0 - 15 and 15 - 70 cm/sec.), showed that there was a significant difference between the two tables in the speed range of 0 - 5 cm/sec. Above 5 cm/sec., it was immaterial which calibration curves were used, whether the segmented ones, or the single one over the full range 0 - 70 cm/sec. Since the segmented curves gave a lower standard deviation for the least-squares fit, it would be then more desirable to use two calibration curves over the full range, rather than the single one.

TABLE 3

Comparison of Speed Calibration Curves

The single calibration curve from 0 - 70 cm/sec. is taken as standard. All speeds are expressed in cm/sec.

Definitions: $\Delta N$ = decimal number difference in 10 min.

$U_s$ = standard calibration, 0 - 70 cm/sec.

$U_1$ = calibration over range 0 - 15 cm/sec.

$U_2$ = calibration over range 15 - 70 cm/sec.

$U_p$ = calibration from standard equation, Plessey Co. Ltd.

$\Delta U_1 = U_1 - U_s$

$\Delta U_2 = U_2 - U_s$

$\Delta U_p = U_p - U_s$

$Pct_1 = (\Delta U_1/U_s) \times 100$ (in %)

$Pct_2 = (\Delta U_2/U_s) \times 100$ "

$Pct_p = (\Delta U_p/U_s) \times 100$ "

| Speeds | | | | | Speed Differences | | | Percent Differences | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\Delta N$ | $U_s$ | $U_1$ | $U_2$ | $U_p$ | $\Delta U_1$ | $\Delta U_2$ | $U_p$ | $Pct_1$ | $Pct_2$ | $Pct_p$ |
| 0 | 1.17 | 1.38 | | 0.03 | 0.21 | | -1.14 | 18.0 | | -97.5 |
| 1 | 1.74 | 1.93 | | 0.63 | 0.19 | | -1.10 | 10.9 | — | -63.8 |
| 2 | 2.30 | 2.48 | | 1.23 | 0.18 | | -1.07 | 7.8 | | -46.5 |
| 3 | 2.87 | 3.02 | | 1.83 | 0.15 | | -1.04 | 5.2 | | -36.2 |
| 4 | 3.43 | 3.57 | | 2.43 | 0.14 | | -1.00 | 4.1 | | -29.2 |
| 5 | 4.00 | 4.12 | | 3.03 | 0.12 | | -0.97 | 3.0 | | -24.2 |
| 6 | 4.56 | 4.67 | | 3.63 | 0.11 | | -0.93 | 2.4 | | -20.4 |
| 7 | 5.13 | 5.21 | | 4.23 | 0.08 | | -0.90 | 1.6 | | -17.5 |
| 8 | 5.70 | 5.76 | | 4.83 | 0.06 | | -0.87 | 1.1 | | -15.2 |
| 9 | 6.26 | 6.31 | | 5.43 | 0.05 | | -0.83 | 0.8 | | -13.3 |
| 10 | 6.83 | 6.86 | | 6.03 | 0.03 | | -0.80 | 0.4 | | -11.7 |
| 15 | 9.66 | 9.60 | | 9.03 | -0.06 | | -0.63 | - 0.6 | | - 6.5 |
| 20 | 12.49 | 12.34 | | 12.03 | -0.15 | | -0.46 | - 1.2 | | - 3.7 |
| 24 | 14.75 | 14.53 | | 14.43 | -0.22 | | -0.32 | - 1.5 | | - 2.2 |
| 25 | 15.31 | | 15.22 | 15.03 | | -0.09 | -0.28 | | -0.6 | - 1.8 |
| 30 | 18.14 | | 18.06 | 18.03 | | -0.08 | -0.11 | | -0.4 | - 0.6 |
| 35 | 20.97 | | 20.90 | 21.04 | | -0.07 | 0.07 | | -0.3 | 0.3 |
| 40 | 23.80 | | 23.74 | 24.04 | | -0.06 | 0.24 | | -0.3 | 1.0 |
| 50 | 29.46 | | 29.42 | 30.04 | | -0.04 | 0.58 | | -0.1 | 2.0 |
| 60 | 35.12 | | 35.10 | 36.04 | | -0.02 | 0.92 | | -0.1 | 2.6 |
| 70 | 40.78 | | 40.78 | 42.04 | | -0.00 | 1.26 | | 0.0 | 3.1 |
| 80 | 46.43 | | 46.45 | 48.04 | | 0.02 | 1.61 | | 0.0 | 3.5 |
| 90 | 52.09 | | 52.13 | 54.04 | | 0.04 | 1.95 | | 0.1 | 3.7 |
| 100 | 57.75 | | 57.81 | 60.04 | | 0.06 | 2.29 | | 0.1 | 4.0 |
| 110 | 63.41 | | 63.49 | 66.05 | | 0.08 | 2.64 | | 0.1 | 4.2 |
| 120 | 69.07 | | 69.17 | 72.05 | | 0.10 | 2.98 | | 0.1 | 4.3 |

# COMPARISON OF SPEED CALIBRATION CURVES

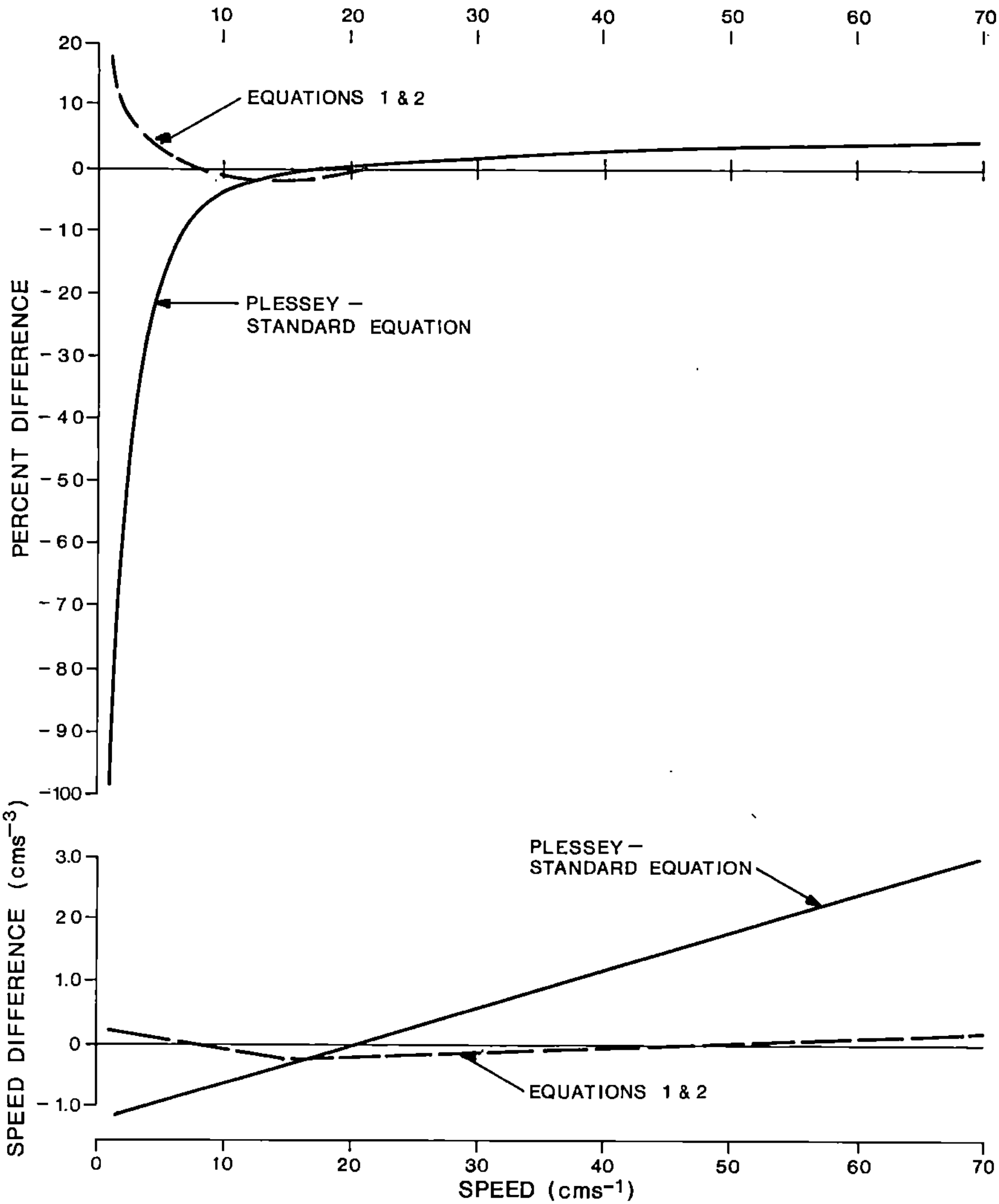



Fig. 6

The manufacturer's calibration curve was too low by amounts ranging from almost 100% to 2%, over the range of 0 - 15 cm/sec; hence, the calibration equation supplied by the manufacturer should not be used.

## VII. REFERENCES

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