Environment Canada
Environnement Canada

Canada Centre For Inland Waters
Centre Canadien Des Eaux Intérieures

AN EXPERIMENTAL OUTLINE TO STUDY THE PERFORMANCE OF THE PRICE CURRENT METER

by

P. Engel

UNPUBLISHED REPORT
RAPPORT NON PUBLIE

AN EXPERIMENTAL OUTLINE TO STUDY THE PERFORMANCE OF THE PRICE CURRENT METER

by

P. Engel

Hydraulics Research Division

Canada Centre for Inland Waters

Burlington, Ontario

May 1977

SUMMARY

An outline of experiments has been presented to implement a detailed study of the performance of the Price current meter. Through dimensional analysis together with examination of available literature, seven dimensionless independent variables have been identified for study, resulting in a total of seven experiments. It is recommended that the execution of this study be an ongoing process resulting in a series of short reports for distribution to meter users.

TABLE OF CONTENTS

AN EXPERIMENTAL OUTLINE TO STUDY THE PERFORMANCE OF THE PRICE CURRENT METER

1.0 INTRODUCTION

In Canada and the U.S. most open channel flow measurements are made using the Price current meter. Considerable expense by government agencies has been incurred in obtaining, using and maintaining these meters. Therefore, it is important to know what factors influence the performance of this instrument. Such knowledge will ensure proper use of this meter in the field and permit calibrations as quickly and efficiently as possible.

This outline was prepared in response to a request by the Technical Services Section of the Hydraulics Research Division to provide some guidance in the evaluation of the Price current meter. In order to obtain this kind of information, a careful and systematic set of experiments should be conducted in which each of the independent variables that affect the performance of the current meter is examined separately. The experiments can be carried out in the hydraulics laboratory at the Canada Centre for Inland Waters which has a large towing tank and other facilities ideally suited for this purpose.

This study outline should be viewed as a basic guide, outlining general discrete steps in the study of one specific instrument. Such a study should be an integral part in striving toward the long term goal of providing detailed information on measurmenet techniques and instruments used for open channel flow.

2.0 SCOPE OF STUDY

The study should include an evaluation of the effects of all those parameters which are known to have an effect or which may logically affect the performance of the Price current meter. These parameters are commonly referred to as the independent variables and there are 14 of these considered here. These independent variables act separately or in concert to affect the dependent variable which is the rate of rotation of the meter rotor N (revolutions/second). It is the essence of this study to separate the effects of these independent variables.

2.1 The Independent Variables

The independent variables can be separated into four groups as follows:

a) Meter Characteristics

D	=	Diameter of rotor	[L]
R	=	Frictional torque due to bearings and contacts	$[ML^2T^{-2}]$

b) Suspension Characteristics

θ	=	Horizontal angular deviation from the direction parallel to the flow.	$[M^\circ L^\circ T^\circ]$
α	=	vertical angular deviation from the direction normal to the flow	$[M^\circ L^\circ T^\circ]$
d	=	depth of the meter below the water surface	[L]
a	=	height of the meter above the suspension weight	[L]
W	=	magnitude and type of weight	$[MLT^{-2}]$

c) Towing Tank Characteristics

T	=	waiting time between successive tests	[L]
d_h	=	distance between meter and vertical tank wall	[L]

d) Fluid Characteristics

V	=	velocity of the fluid	$[LT^{-1}]$
μ	=	viscosity of the fluid	$[ML^{-1}T^{-1}]$
ρ	=	density of the fluid	$[ML^{-3}]$
$\sqrt{\bar{u}^2}$	=	root mean square value of velocity fluctuations	$[LT^{-1}]$

e) Earth

g	=	acceleration owing to gravity	$[LT^{-2}]$

Variables according to their group are defined schematically in Figure 2.1.

2.2 Dimensional Analysis

The independent variables can be most efficiently organized by dimensional theory. Taking D, V and R as the characteristic variables, then the dependent variable N can be expressed as:

$$\frac{ND}{V} = \phi\left[\frac{\mu VD^2}{R}, \frac{\rho V^2 D^3}{R}, \frac{V}{\sqrt{gD}}, \frac{VT}{D}, \frac{\sqrt{\bar{u}^2}}{V}, \frac{a}{D}, \frac{d_n}{D}, \theta, \alpha, \frac{d}{D}, W\right] \quad \text{....... 2.1}$$

where: ϕ denotes a function

N = rate of rotation of rotor in rev/s.

It was shown by Engel (1976) that viscosity of the fluid was not important and hence $\frac{\mu VD^2}{R}$ may be dropped from equation 2.1. Since the effect of fluid density has already been investigated previously, Engel (1976), it will not form part of this investigation. However, it will be kept constant during investigations of the other parameters. Gravity will have a negligible effect as long as surface waves do not affect the motion of the meter rotor. Since the depth of the towing tank at the hydraulics laboratory has a depth of three meters, the effect of the term $\frac{V}{\sqrt{gD}}$ will be negligible as long as the velocity (towing speed) is less than 540 cm/s. Consequently $\frac{V}{\sqrt{gD}}$ may also be dropped from equation 2.1. Equation 2.1 is now reduced to:

$$\frac{ND}{V} = \phi_2\left[\frac{\rho V^2 D^3}{D}, \frac{VT}{D}, \frac{\sqrt{\bar{u}^2}}{V}, \frac{a}{D}, \frac{dn}{D}, \theta, \alpha, \frac{d}{D}, W\right] \ldots \quad 2.2$$

The magnitude of the suspension weight itself is not important in the context of this study. Rather, the shape and its hydrodynamic influence on the meter is to be considered. Therefore, each function ϕ is unique for each suspension weight and equation 2.2. is more aptly expressed as:

$$\frac{ND}{V} = \phi_W\left[\frac{\rho V^2 D^3}{R}, \frac{VT}{D}, \frac{\bar{u}^2}{V}, \frac{a}{D}, \frac{dn}{D}, \theta, \alpha, \frac{d}{D}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2.3$$

Experiments must be designed so that each one of the independent variables can be varied separately while all the others are made to have an insignificant effect on the dependent variable or are kept constant. Because of the number of independent variables involved, care in designing the experiments must be taken in order to keep the number of tests from becoming unduly large.

3.0 ORGANIZATION OF THE EXPERIMENTS

In conducting these experiments it is very important that a uniform set of standards be adopted which will be strictly adhered to throughout the study. This is vital in order to make a meaningful relative comparison of the effect of the different independent variables.

3.1 Conditions for Keeping Independent Variables Insignificant or Constant During Experiments

While one of the independent variables is being varied, it is important that the remaining independent variables are kept constant or insignificant. This condition for each variable should be taken as follows:

- T : This variable will be tested first and results from these tests will indicate the waiting times required to ensure that this parameter will have no effect.
- $\sqrt{u^2}$: This variable will be tested after T to assess how its effect, if any, must be taken into account.
- $\theta = 0°$
- $\alpha = 0°$
- W : A 50 lb Columbus weight
- a : Large hanger bar to keep meter from weight influence
- d : Set the meter at three feet below the water surface
- dn : Suspend meter in the middle of the towing tank
- D : The diameter is kept fixed by using the same meter throughout the experiments.

3.2 EXPERIMENTS

Experiments should be identified separately by the independent variable that is being studied. A general outline of the required experiments is given under the headings below.

3.2.1 Experiment #1. Waiting Time Between Successive Tests $\frac{VT}{D}$

Each time that a current meter is towed through the water, the water is disturbed and turbulence is set up, the effect of which is not precisely known. In the past, it has been the practice to arbitrarily assume a waiting time (such as ten minutes) in an attempt to eliminate the residual turbulence effect.

In order to assess the significance of waiting times the following tests should be made to evaluate the relationship:

$$\frac{ND}{V} = \phi_{W=50} \left[\frac{VT}{D}\right] \qquad \text{3.1}$$

All the other independent variables should be set as outlined in Section 3.1. Tests will be made by selecting a given velocity V and keeping this constant while T is varied over a suitable range. This will be repeated for other constant velocities, until the necessary velocity range has been covered. The result will be a set of curves which may be as shown schematically in Figure 3.1. For each one of the curves, all the independent dimensionless variables are then constant except for $\frac{VT}{D}$. If waiting time has no effect on N, then the curves will be horizontal lines.

3.2.2 Experiment #2. Turbulence $\frac{\sqrt{\bar{u}^2}}{V}$

Although Experiment #1 deals with turbulence, it does so indirectly. In the towing tank, as waiting time increases, turbulence decreases because of the viscosity of the fluid. In open channel flow, however, turbulence is present all the time. Therefore, direct tests to assess its importance should be conducted. These tests should be done a) in a flume and b) in the towing tank.

a) Tests in the Flume

The simplest and most direct way is testing in a flume. The meter is placed in the flow and turbulence is controlled by placing screens of various mesh sizes upstream at a fixed distance from the meter. The turbulence intensity is obtained by measuring the fluctuations in velocity about the mean velocity at the meter location. The use of different screen sizes will give different turbulence intensities, thus permitting a variation of the variable $\sqrt{\bar{u}^2}$, resulting in the fuctional relationship:

$$\frac{ND}{V} = \phi_{flume}\left[\frac{\sqrt{\bar{u}^2}}{V}\right] \quad \text{.......... } 3.2$$

The same weight as in Experiment #1 should be used and other independent variables kept invariant as before.

Tests will be run by selecting a given velocity and a fixed depth of flow. When this velocity V has been measured, a screen of a given size will be placed a suitable distance upstream of the meter and the variable $\sqrt{\bar{u}^2}$ measured. Then keeping the same velocity V and repeating the procedure using several other mesh sizes, the data can be used to plot a curve for that fixed velocity. The procedure can then be repeated for a different velocity, each such velocity yielding another curve. The result will be a family of curves similar to that shown schematically in Figure 3.1.

b) Tests in the Towing Tank

The tests can be conducted in the towing tank by towing the meter with a screen mounted a fixed distance ahead of it. The distance should be the same as in the flume tests. The procedure is the same as in the flume.

Conducting the tests in the two facilities has the advantage of obtaining data for open channel flow conditions and the towing conditions through still water. The data will make it possible to resolve the old question of whether towing tank calibrations are truly representative of open channel flow conditions.

Experiment #3. Effect of Meter Depth $\frac{d}{D}$

Current meters are used to measure vertical velocity profiles, and velocities near the surface are of interest. Calibrations in towing tanks are done by setting the current meter arbitrarily some "safe" distance below the water surface. Therefore, tests are required to see how close to the surface the Price meter can be used with confidence.

Tests will be run by selecting a velocity V and, while holding this fixed, testing the meter for several depths below the water surface. This results in a set of points to plot the relationship:

$$\frac{ND}{V} = \phi_{W=50} \left[\frac{d}{D}\right] \qquad 3.3$$

The procedure is repeated for other velocities, each such velocity having associated with it another curve. The result will be a family of curves similar to that shown schematically in Figure 3.1.

Experiment #4. Effect of Vertical Boundaries (Towing Tank Wall) $\frac{dn}{D}$

Discharge measurements are often made from a bridge which requires velocity measurements near the piers. Measurements in artificial channels (ie: canals) and flumes require placement of the meter near the side walls. It is therefore important to know how close to a wall a meter can be placed before its performance becomes affected. Such knowledge is also important for the calibration of the meters.

Tests will be conducted by selecting a velocity and, while holding this and other parameters constant, varying the distance dn from the wall of the towing tank. This results in a set of points to plot the relationship.

$$\frac{ND}{V} = \phi_{W=50} \left[\frac{dn}{D}\right] \qquad \text{.......... 3.4}$$

The procedure is then repeated for several other velocities holding each one fixed while varing d_n over the desired range. This will yield a family of curves similar to that shown schematically in Figure 3.1.

<u>Experiment #5. Effect of Instrument Position above the Suspension Weight</u> $\frac{a}{D}$

Current meters are used with different sizes of suspension weights, depending on the flow conditions. It is therefore important to find out:

a) how far away from a given weight the meter should be placed so that it is not affected by the weight.

b) if it is necessary to supply a separate calibration for each different weight as presently used.

Tests will be conducted by selecting a given velocity and holding this fixed while towing the meter at different distances "a" above a chosen weight. This will provide data to construct a curve of the relationship.

$$\frac{ND}{V} = \phi_{W} \left[\frac{a}{D}\right] \qquad \text{.......... 3.5}$$

where: ϕ_W represents a function for a specific suspension weight W.

The procedure is repeated with different velocities but using the same weight. The result will then be a family of curves similar to that shown schematically in Figure 3.1. Such a set of curves will be produced for each weight used. The relationships obtained for each weight can then be used for comparison to assess the effect of each weight as presently used by Water Survey of Canada in the field.

Experiment #6. Horizontal Deviation in Meter Alignment with the Flow θ

It has been observed that Price meters give erroneous readings when they are not alligned parallel to the flow. Such conditions arise when measurements are made where the flow is not at right angles to the measuring traverse and rod suspensions are used. This discrepancy differs also for angles left and right from the true meter position. Some experiments on this phenomenon have been made by Grindley (1971) and others. However, additional tests should be conducted since the procedures are rigidly controlled in these experiments.

In order to achieve the angular control, the meters will be mounted on a rod. Then, for a fixed velocity, the meter should be tested for several angles both to the left and right. This will result in data to plot the relationship:

$$\frac{ND}{V} = \phi_R \left[\theta\right] \quad \text{......} \quad 3.6$$

where: ϕ_R is the function for rod suspension.

The procedure is then repeated for other velocities, while other variables are kept properly controlled. The end result is a set of curves as shown schematically in Figure 3.1.

Experiment #7. Vertical Deviation of Meter Alignment with the Flow

Vertical deviation of meters may occur when they are suspended by a rod due to rod deflection or improper alignment when placed in the flow. Such deviations may also occur for cable suspended meters, when they are not permitted to "swivel" freely while the suspension is deflected by the flow.

Tests should be conducted to assess the effect of this vertical deviation. These tests will be conducted using the same procedure followed in Experiment #6. The end result will be a set of curves which define the relationship:

$$\frac{ND}{V} = \phi_R \left[\frac{\alpha}{D} \right] \qquad 3.7$$

Such a set of curves is similar to that shown schematically in Figure 3.1.

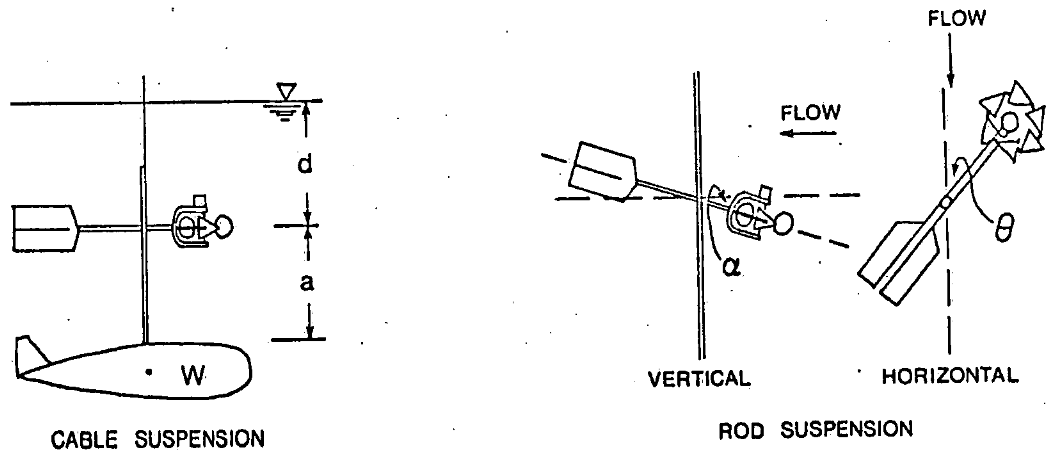
4.0 ORGANIZATION OF EXPERIMENTAL RESULTS

The results from the experiments can be conveniently produced as a series of Technical Notes. Such a report series has the advantage of providing, immediately, test results to meter users across the country since the complete study may take considerable time to complete. Such brief reports also have the advantage of providing a base for discussion of results with Water Survey of Canada to obtain feedback and additional information which can be used in a final report upon completion of the study. The final report should then be published in a suitable publication.

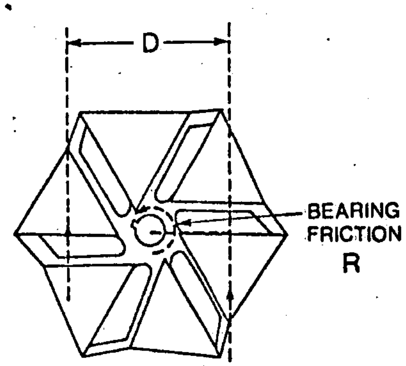
REFERENCES

1. Grindley, J., 1971. Behaviour and Calibration of Current Meters. Internal Report No. 95, Hydraulics Research Station, Wallingford, Berkshire, England.

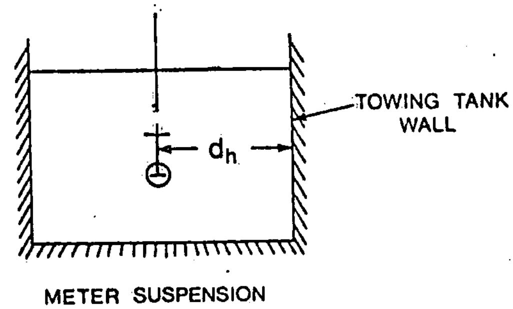
2. Engel, P., 1976. A Universal Calibration Equation for Price Meters and Similar Instruments. Scientific Series No. 65, Inland Waters Directorate, Canada Centre for Inland Waters, Burlington, Ontario.



A. SUSPENSION CHARACTERISTICS



B. METER CHARACTERISTICS



C. TOWING TANK CHARACTERISTICS

FIGURE 2.1 DEFINITION OF INDEPENDENT VARIABLES (EXCLUDING FLUID AND EARTH CHARACTERISTICS)

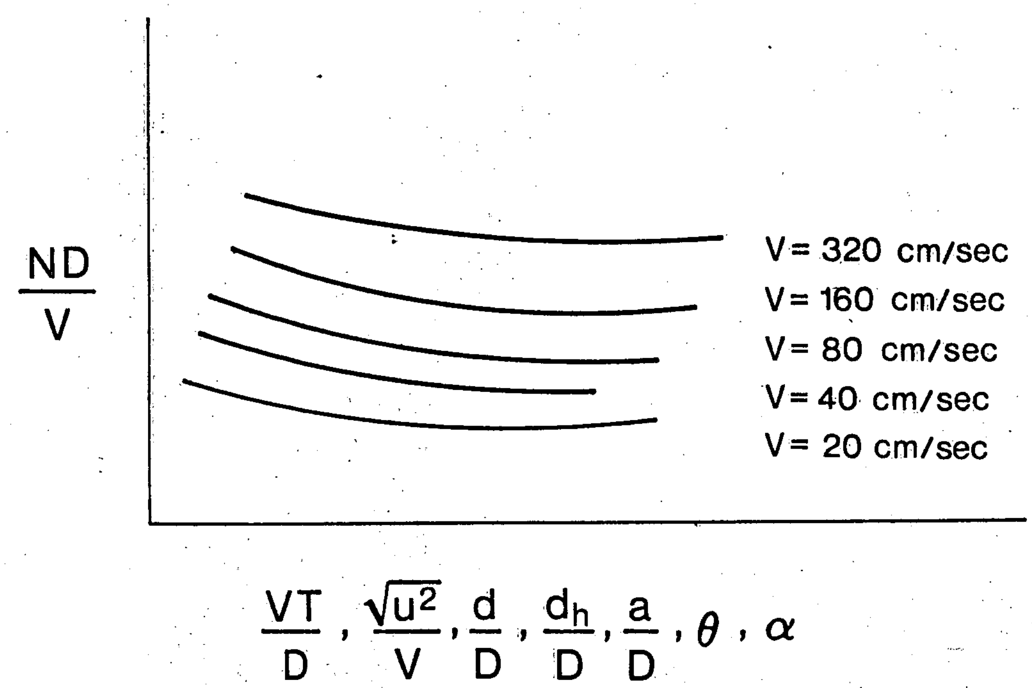


FIGURE 3.1 SCHEMATIC SET OF CURVES FOR INDEPENDENT VARIABLES.