NAVY DEPARTMENT
DAVID TAYLOR MODEL BASIN
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ELECTRONIC METHODS OF OBSERVATION at the David W. Taylor Model Basin

PART 9
A PHOTOELECTRIC TIME-INTERVAL METER FOR INSTANTANEOUS VELOCITY MEASUREMENTS

by
Lt. G. Robert Mezger, USNR

[redacted]

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PERSONNEL

The instrument described in this report was developed by George W. Cook of the Electronics Service Section and was constructed by members of that section. The report was prepared by Lt. G. Robert Mezger, USNR.

FOREWORD

This is the ninth report of a series under preparation to make available to other experimental and research activities the results of developments at the David Taylor Model Basin in the application of electronic methods of observation to a great number of naval problems other than those of communication.

This report is of the nature of an interim report in that it describes merely the present state of development of an instrument whose design is considered still incomplete. In its present form, however, the device has proved sufficiently useful to warrant a report describing its operation and maintenance.

It is planned to prepare and publish a comprehensive report on a more thoroughly developed instrument as soon as the requirements for equipment of this type permit assigning a higher priority to the project.

A PHOTOELECTRIC TIME-INTERVAL METER FOR INSTANTANEOUS VELOCITY MEASUREMENTS

ABSTRACT

An electronic instrument is described which can measure short intervals of time, and which can be used for velocity measurements under conditions which make it essentially direct-reading.

The instrument is actuated by the interruption of a light beam which impinges upon a photoelectric cell. Interruption of the light beam changes the charge on a condenser, the potential of which is measured by a vacuum-tube voltmeter to give an indication of time interval.

Details of the construction and operation of the instrument are given.

INTRODUCTION

The study of objects in motion frequently requires a simple, accurate, reliable, and rapid means for the measurement of instantaneous velocity. Both mechanical and photographic methods for these measurements have been employed at the David Taylor Model Basin. They all have been found, however, to possess inherent disadvantages which have intensified the search for a simpler method.

Electrical methods for the measurement of time seemed to offer a solution to this problem. By the measurement of a time interval, the time rate of motion of an object past a given point can be determined easily. Electrical methods for measurement of time were known to exist, and the problem was placed before the Electronics Section of the Taylor Model Basin. At the time, there was an urgent need for the solution to a difficult problem in velocity measurement, and the equipment described in this report was prepared to meet that requirement.

The basic method for measurement of velocity, for which the photoelectric time-interval meter was employed, is shown in the diagram of Figure 1. The object whose velocity is to be measured carries a vane which interrupts the beam of light to a photoelectric cell for a short interval of time. The velocity may be calculated from the reading of the time-interval meter when the length of the vane which interrupts the light beam is known.

TYPICAL APPLICATION OF THE INSTRUMENT

Over the range for which the instrument is designed, it should be possible, in general, to employ it for the measurement of a time interval in any case where this interval can be related to the interruption of a light beam. The only requirements are that there be, on the object or on a vane carried by the object, sharp edges at right angles to the direction of motion, and that it be practicable to mount a light source and a photoelectric cell reasonably close together, on opposite sides of the object, at the point where its instantaneous velocity is to be determined.

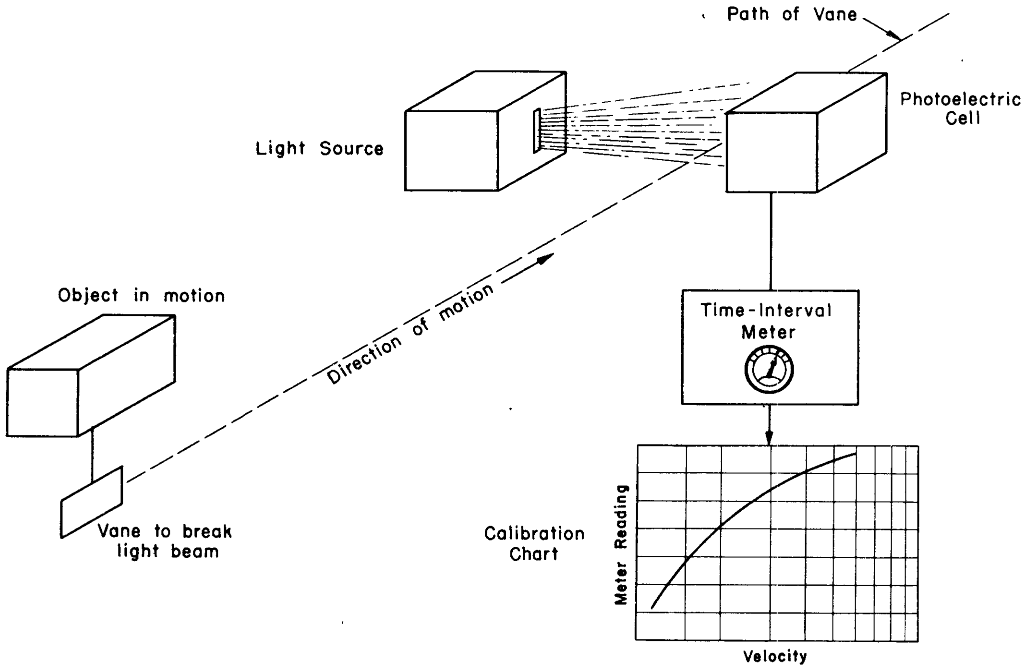

Figure 1 - Diagram of Method for Electrical Measurement of Velocity

Two cases in which it has recently been employed with success for velocity measurement at the Taylor Model Basin may be worth mentioning.

For the measurement of the instantaneous velocity of Towing Carriage 4, a thin sheet-steel vane, 12 inches long and approximately 4 inches high, was mounted on the carriage. The lamp house and the photoelectric-cell house were mounted along the track at the point at which it was desired to determine the speed of the carriage. The vane was located on the carriage so that it intercepted the beam of light. By the use of the curve shown in Figure 3, the speed of the carriage was determined. This curve was plotted from data obtained by calculation from the results of experiments with a calibrated pendulum, bearing a light-intercepting vane, which intercepted the beam of light. These data were checked further against the results obtained from test runs of Carriage 1, the speed of which is known accurately.

In another instance, it became necessary to measure the instantaneous velocity of a model being catapulted into the air at the point where it left the catapult. It was necessary to know the terminal velocity at once so that the catapulting force could be continually adjusted to produce a specified speed.

When the instrument is set prior to a run, it functions automatically, and the meter reading remains fixed until it can be read off and the instrument reset. No instantaneous readings of a fast-moving pointer are necessary. Entering the calibration curve with the meter reading gives the speed in one operation.

DESCRIPTION OF CIRCUIT

A schematic diagram of the circuit of the meter is given in Figure 2. The instrument is built in three units: a lamp house which contains the source of light to actuate the photoelectric cell; a phototube housing which contains the phototube and a cathode-follower impedance transformer; and a larger chassis which mounts the remainder of the circuit and the power supplies.

Referring to Figure 2, V_3 is the light source which actuates the photocell. V_1 is the photocell and V_2 is the impedance transformer. This feeds the signal, developed at a high-impedance level by the photocell, into a low-impedance cable which couples to the remainder of the circuit. For any time during which no light impinges upon the cathode of the photocell, tube V_7 will draw current from C_1. Tube V_5 is a vacuum-tube voltmeter which measures the charge on C_1 at all times. A change in charge upon C_1 is indicated by the change in plate current of V_5, which is shown in turn on M_1. Other elements of the circuit exercise various protective and service functions, and their uses will be described in the detailed description of the operation of the circuit which is given in the following.

For analyzing the operation of the circuit, consider that illumination of the proper intensity is supplied to the cathode of the phototube V_1. Under this condition, the grid of V_2 is held negative, the cathode of V_2 is driven negative, and through R_9, the grid of V_7 is held negatively beyond cutoff potential. With switch S_1 in the "down" position, no current is drawn from condenser C_1 by V_7. Even though the grid of V_2 may be carried to cutoff potential by the potential which is developed by V_1, the cathode of V_2 is prevented from reaching -250 volts because of the voltage drop which is produced across R_9 and R_{10} by the current drawn by the left-hand diode section of the Type 6H6 diode, V_4. Similarly, the right-hand diode section of V_4 prevents the grid of V_7 from going more positive than -75 volts, and this action serves as a protection to the life of the meter in the cathode of V_5; in addition, this diode section insures that at the start of the conduction period the grid of tube V_7 always starts from exactly the same potential. This insures stability of the calibration of the device.

For the measurement of an interval of time with the instrument, switch S_1 is thrown first to the "center" position. With the switch in this position, condenser C_1 is charged to a predetermined value. Switch S_1 then is moved to its "down" position. When the passage of light from V_3 to V_1 is interrupted by some means, such as the vane shown in Figure 1, or by the object itself, the grid of V_2 is driven in a positive direction, and this carries the grid of V_7 in a positive direction to a point where V_7 draws current from C_1. Current is drawn from C_1 until light is again permitted to impinge upon the cathode of V_1.

When the illumination returns, the grid of V_7 is returned to a point beyond cutoff potential, and the new charge on C_1 which is measured by V_5 is indicated on M_1. It will be noted that meter M_1 reads a maximum current when condenser C_1 is fully

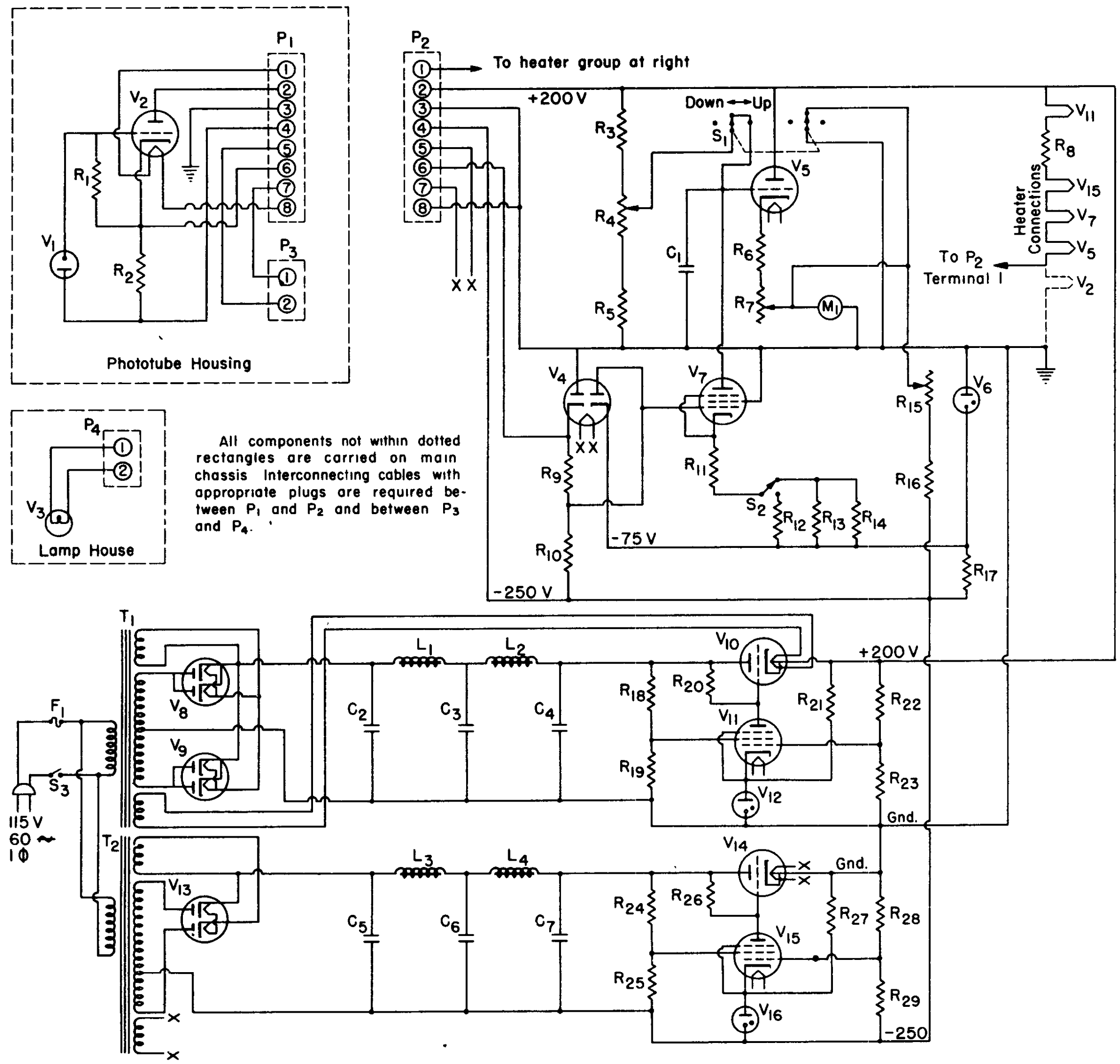

Figure 2 - Schematic Diagram of the Circuit of a Photoelectric Time-Interval Meter

Parts List

R_1 - 2 M, 1/2 w
R_2 - 200 K, 1 w
R_3 - 70 K, 1 w
R_4 - 10 K, wirewound potentiometer
R_5 - 20 K, 1 w
R_6 - 5 K, 1 w
R_7 - 1 K, wirewound potentiometer
R_8 - 1 K, 10 w
R_9 - 100 K, 1 w
R_{10} - 150 K, 1 w
R_{11} - 1 K, 1 w
R_{12} - 40 K, 1 w
R_{13} - 2 K, 1 w
R_{14} - 12.5 K, 1 w
R_{15} - 3 K, wirewound potentiometer
R_{16} - 40 K, 1 w
R_{17} - 6 K, 10 w
R_{18} - 100 K, 1 w
R_{19} - 100 K, 1 w
R_{20} - 500 K, 1 w
R_{21} - 4.5 K, 10 w
R_{22} - 100 K, 1 w
R_{23} - 100 K, 1 w
R_{24} - 100 K, 1 w
R_{25} - 100 K, 1 w
R_{26} - 500 K, 1 w
R_{27} - 4.5 K, 10 w
R_{28} - 100 K, 1 w
R_{29} - 100 K, 1 w

Parts List (continued)

C_1 - 4 mu f, 600 v, oil impregnated
C_2 - 4 mu f, 600 v, oil impregnated
C_3 - 4 mu f, 600 v, oil impregnated
C_4 - 8 mu f, 500 v, electrolytic
C_5 - 8 mu f, 450 v, electrolytic
C_6 - 8 mu f, 450 v, electrolytic
C_7 - 8 mu f, 500 v, electrolytic

V_1 - High-vacuum phototube, Type 922
V_2 - 12SF5
V_3 - Mazda 1130, 21 cp, 6-8 v, double-contact bayonet base
V_4 - 6H6
V_5 - 12J5
V_6 - VR75/30
V_7 - 12SJ7
V_8 - 5Z4
V_9 - 5Z4
V_{10} - 6A5
V_{11} - 12SJ7
V_{12} - VR105/30
V_{13} - 5Z4
V_{14} - 6A5
V_{15} - 12SJ7
V_{16} - VR105/30

F_1 - 2 amp fuse, Type 3AG

Note: The unit for all resistance values given in this table is ohms. K is a multiplying factor equal to 10^3. M is a multiplying factor equal to 10^6.

T_1 - Power transformer, primary, 115 volts, 60 cycles; secondaries, 400-0-400, 200 ma; 5 v, 4 amp; 6.3 v, 5.14 amp, center-tapped; Thordarson Type 13R16

T_2 - Power transformer, primary, 115 volts, 60 cycles; secondaries, 350-0-350, 120 ma; 5 v, 4 amp; 6.3 v, 4.7 amp, center-tapped; Thordarson Type 13R14

L_1, L_2 - Filter choke, 12 h at 0 ma, 5 h at 200 ma, Thordarson T67C49

L_3, L_4 - Filter choke, 27 h at 0 ma, 10 h at 110 ma, Thordarson T57C53

S_1 - Two-circuit, three-position, spring-return, lever-type switch
S_2 - SPDT rotary switch
S_3 - SPST toggle switch

P_1 - Eight-contact plug with recessed plate, Jones P-308-RP
P_2 - Eight-contact socket with flush plate, Jones S-308-FP
P_3 - Four-contact socket with flush plate, Jones S-304-FP
P_4 - Four-contact plug with recessed plate, Jones P-304-RP

M_1 - Weston milliameter, Model 301, 0-5 ma, d-c

charged, and the current indicated by M_1 decreases as the time interval increases. M_1 is adjusted to read full-scale current with S_1 in its "up" position by control of R_7, which is mounted on the front panel of the instrument.

The switch S_2 is a range switch. This switch determines the amount of resistance in the cathode circuit of V_7. Thus it determines the current drawn by V_7 and therefore the time rate of discharge of C_1 by V_7. The position for S_2 which yields the lowest value of cathode-circuit resistance is the position for measurement of the shortest time intervals. A calibration of the instrument for this position is given in Figure 3. Calibration of the instrument on the other position of S_2 has not yet been completed.

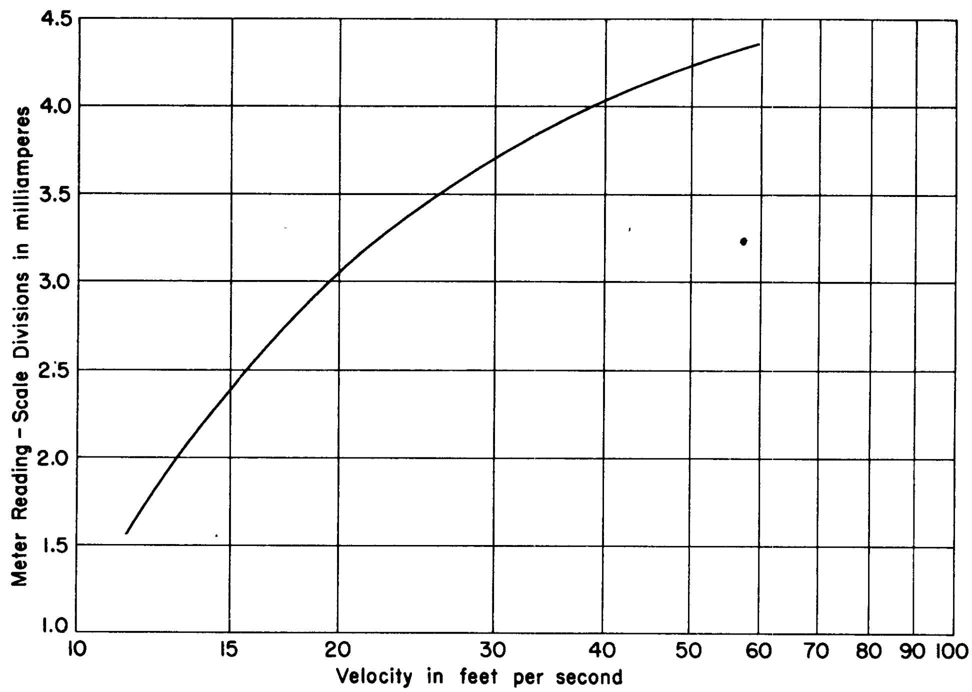

Figure 3 - Typical Calibration Curve of Photoelectric Time-Interval Meter

The power supplies for operation of the circuit are conventional full-wave rectifier-filter systems, the outputs of which are controlled by electronic voltage regulators. The regulators have been designed to operate satisfactorily under average conditions, and no adjustments have been provided. The operation of this general type of regulator is discussed in TMB Report 502, "An Electronic Voltage Regulator."

ADJUSTMENT OF THE CIRCUIT

During operation of the instrument, when all other circuit constants are in proper adjustment, the rheostat R_7 on the front panel of the instrument should be adjusted to give full-scale deflection of the meter M_1 with S_1 in its "up" position.

From inspection of the circuit, it is apparent that if M_1 were to indicate the total cathode current of V_5, considerable error would exist on measurements of long time intervals where this current may become quite low. In these cases, a considerable portion of the time-interval scale would be located on the curved portion of the i_p-e_g characteristic of V_5. To obviate this difficulty, the circuit is arranged so that the meter M_1 indicates over the linear portion of the tube characteristic.

That is, the meter reads zero current at the bottom of the essentially straight portion of the characteristic, and it reads full scale near the top of this portion of the tube characteristic. This is shown graphically in Figure 4.

Adjustment of the circuit so that the meter operates over the essentially linear portion of the operating characteristic of V_5 will remain constant for an indefinite period. It is accomplished by adjustment of R_{15} and R_4 so that the meter indicates equal changes in current for equal intervals of time over its entire scale range.

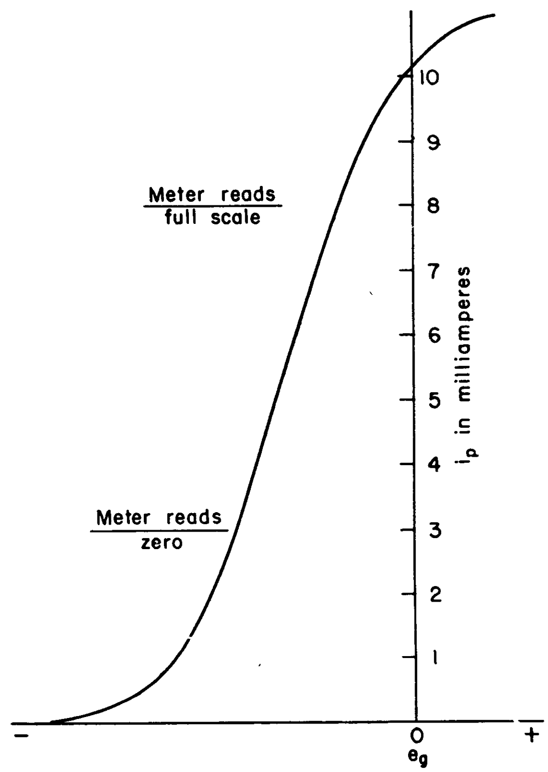

Figure 4 - Location of Meter Scale on Operating Characteristic of Tube V_5

This is accomplished by mounting a vane on a pendulum to intercept the light entering the photocell. The length of the vane and the period of the pendulum are so chosen that when the pendulum makes one swing and intercepts the light beam once, the decrease in current through M_1 is approximately 1/5 of the full-scale current of the meter. The pendulum is then permitted to swing up to 5 times, and R_4 and R_{15} are adjusted so that each pass of the vane between the photocell and the light source produces exactly the same change in current through the meter. When the circuit is properly adjusted so that the meter is indicating over the linear portion of the operating characteristic of V_5, these time intervals will be equal.

It has been found that the distance between the photocell V_1 and the light source V_3 will affect the accuracy of the instrument. The photocell must not be overloaded, as it would be if the distance between these two tubes were too small, and the illumination must not be too small, as it may be if this distance is too great. It has been determined empirically that, with the photocell and light source which are used with this equipment, the distance between these two tubes must be not less than 18 inches nor more than 21 inches.

Calibration of the instrument, as well as adjustment of the circuit, may be accomplished by a pendulum with a light-intercepting vane attached as outlined in the foregoing.

The accuracy of the instrument is not known at the present time. It has been found possible to reproduce its readings consistently within the accuracy of reading the meter. The instrument's accuracy, therefore, must be limited by the accuracy of the calibrating method plus personal errors in reading.

CONCLUSIONS

It is believed that more extended use of the apparatus described in this report will lead to the further development and refinement of the design. The instrument now gives the average velocity for the length of time needed for the vane or the object to pass a given point, but this interval can be made reasonably small.

It may eventually be possible to make the instrument direct-reading in velocity, should this become necessary, without the necessity for making a specially graduated dial for the meter.