FOR UNITED STATES GOVERNMENT USE ONLY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

INVESTIGATION OF A 4-INCH MAGNETIC FLOWMETER

Report No. Hyd-574

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

May 19, 1967

CONTENTS

ABSTRACT

A 4-in. magnetic flowmeter was studied to determine its operating characteristics, accuracy, and general performance. The discharge range of the meter was 22 to 1320 gpm (0.05 to 2.94 cfs). The range is made adjustable by the manufacturer into 3 subranges of 22 to 220, 66 to 660, and 130 to 1320 gpm. At the minimum discharges for each subrange, the meter read from 1 to 2% high. An accuracy of plus or minus 1% of the rate of flow was obtained for about the upper 80% of each subrange. Control of the flow with a gate valve located 15 dia upstream or downstream from the meter had negligible effect on the meter accuracy. Controlling the flow with a valve at the inlet to the meter caused the indicated discharge to be 4% higher than the actual discharge. Operation of the meter was generally satisfactory, but a failure of an electronic component after 1 month's use raised a question on system reliability.
DESCRIPTORS-- magnetic fields/ electric potential/ hydraulics/ meters/ *water meters/ *flow meters/ closed conduits/ pipelines/ *water measurement/ laboratory tests/ calibrations/ performance tests
IDENTIFIERS-- Fischer-Porter flow meter/ product evaluation/ magnetic flow meters

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Office of Chief Engineer
Division of Research
Hydraulics Branch
Special Investigations Section
May 19, 1967

Report No. Hyd-574
Authors: C. E. Brockway
J. C. Schuster
Reviewed by: A. J. Peterka
Submitted by: H. M. Martin

INTRODUCTION

Water-measuring devices used in closed conduit systems on Bureau of Reclamation irrigation projects have been propeller- or differential-type meters. The Venturi meter has received general use in large capacity turnouts. Because of the limited discharge range of an individual meter (about 10 to 1), several Venturi meters or sizes are necessary for each turnout. Magnetic flowmeters having a larger discharge measurement range (about 30 to 1) and essentially zero head loss might reduce the complexity of an installation but have not been used on Bureau projects.

Delivery of water to the Westlands Irrigation District from the San Luis Canal requires measurement over a large discharge range. The Fischer-Porter Company asked that their magnetic flowmeter system be considered in the specifications as an alternative installation to Venturi meters in the turnouts. With capacity for measurement of a wider discharge range, fewer magnetic meters would be required for a turnout. The magnetic meter might then become economically competitive. Bureau designers being interested in the possible use of the meters suggested making a study of the accuracy, capability, discharge range, and the reliability of the meter and electronic system.

SUMMARY

A 4-inch magnetic flowmeter manufactured by the Fischer-Porter Company, Warminster, Pennsylvania, was investigated in the Hydraulics Laboratory. The purpose of the investigation was to determine the operating characteristics, accuracy, and general performance of the meter.

The meter primary, or measuring system, Figure 1A, was installed in a 4-inch standard pipe with gate valves 15 diameters upstream and 15 diameters downstream, Figure 3A. Both of these valves were used for discharge controls. For subsequent tests, the upstream gate valve was installed at the inlet to the meter, Figure 3B, to determine whether or not the velocity disturbance caused by the valve affected the meter accuracy. The meter secondary or readout system, Figure 1B, included a converter or transducer, a single pen recorder and a digital counter or integrator. Actual discharges through the meter were measured with the permanent volumetric calibration facilities in the laboratory.

The discharge range of the meter is 22 to 1,320 gpm (gallons per minute) (1.4 to 83.2 l/s). The meter range is made adjustable by the manufacturer into three subranges of 22 to 220, 66 to 660 and 130 to 1,320 gpm. By subdividing the discharge range, better accuracies are claimed by the manufacturer throughout the flow range of the meter. These subranges could be selected by a range selector switch in the converter.

The manufacturer claimed a discharge measurement accuracy of plus or minus 1 percent of the maximum discharge for 10 to 100 percent of the flow of each subrange. The meter met the specifications except for the smaller discharges of each range. At the minimum discharges (0 to 10 percent) for each subrange the meter read from 1 to 2 percent high. When the valve at the inlet to the meter was used to control the flow, the meter indicated discharge was as much as 4 percent higher than actual discharge. An accuracy of plus or minus 1 percent of rate was obtained for about the upper 80 percent of each subrange.

Controlling the flow with a gate valve located 15 diameters upstream or downstream from the meter had negligible effect on the meter accuracy. Controlling the flow by a partially opened valve at the inlet to the meter is not recommended.

The converter, a part of the meter secondary, failed to function properly after about 1 month's operation in the laboratory and was returned to the factory for repair. This failure under laboratory conditions raises a question as to the reliability of the system under field conditions.

LABORATORY TEST INSTALLATION

Meter Description

The magnetic flowmeter works on the principle of induction as stated by Faraday's law. When an electrical conductor is moved through a magnetic field at right angles to the field, an emf (electromotive force or voltage) is produced in the conductor. The generated voltage is directly proportional to the velocity of the conductor.

A uniform parallel magnetic field is generated by alternating-current coils. The coils are mounted diametrically opposite on the outside of the pipe forming the meter flow tube. The water is the conductor. A voltage is generated between two electrodes placed on a diameter of the tube at right angles to the magnetic field and flow direction. The resulting alternating-current voltage is measured by electronic components and used to indicate the volumetric rate of flow. The discharge, proportional to the velocity and pipe area, is therefore directly proportional to the voltage because the flow tube area is constant.

The primary component of the 4-inch Fischer-Porter flowmeter contained the magnetic coils, a nonmagnetic flow tube of stainless steel lined with neoprene, and the electrodes, Figure 1A. The rated velocity range for the primary was 0.5 fps (feet per second) (0.15 m/s) to 30 fps (9.14 m/s). The corresponding discharge range for this flow tube having an inside diameter of 3.917 inches (9.949 cm (centimeter)), would be 0.043 to 2.57 cfs (cubic feet per second) (19.2 to 1,150 gpm) (12.1 to 70.2 l/s). However, the measured discharge range was 22 to 1,320 gpm.

The secondary system of this meter included a "converter" for converting the alternating-current voltage output of the primary to a proportional direct-current output, a single pen strip chart recorder operating from the converter output signal, and an electromechanical counter or integrator operating on a 24-volt direct-current pulsed signal from the converter, Figures 1 and 2. The converter or main component of the secondary or readout system was equipped with a meter and scale reading in percent of maximum flow for the selected range, Figure 1, and a velocity range selector switch, Figure 2A.

The full velocity range, 0.5 to 30 fps (0.15 to 9.14 m/s) was divided into three subranges which could be set on the converter depending on the discharge. The three subranges used were 0.5 to 5 fps (0.15 to 1.52 m/s), 1.5 to 15 fps (.45 to 4.57 m/s) and 3 to 30 fps (0.91 to 9.14 m/s).

The strip chart recorder had been specially furnished with a speed of 2-5/8 inches per minute (6.57 cm/m) and a scale range from 0 to 1,200 gpm (0 to 75.6 l/s), Figure 2B. The normal chart speed is seven-eighths inch per hour (2 cm/hr) and for this speed one chart roll will last about 1 month. The electromechanical counter for totaling the flow in volume units (gpm or cfs) had a six-digit dial with a manual reset. The counter has a maximum speed of 25 impulses per second. The manufacturers guaranteed accuracy was restricted to discharges corresponding to a range from 10 to 100 percent of maximum flow for the selected velocity range. The accuracy for the complete magnetic flowmeter system was stated by the manufacturer as: (1) 3-fps maximum flow velocity or above--plus or minus 1 percent of full scale of the selected range, (2) 1-fps maximum flow velocity--plus or minus 2 percent of full scale of the selected range, (3) reproducibility--plus or minus one-half percent of selected full scale or better.

Meter Installation

The 4-inch magnetic flowmeter was installed in the laboratory piping system Figure 3A. Standard 4-inch pipe with a gate valve 15 diameters upstream and 15 diameters downstream was used for the meter installation. The upstream valve was later moved to a position at the inlet of the flow tube of the meter primary, Figure 3B. Water could be pumped through the flowmeter and into a volumetric calibration tank. The calibration tank is a standard of discharge measurement used in the laboratory.

The flowmeter primary was connected in the laboratory tests to the secondary system with No. 14 wire as recommended by the manufacturer for commercial meter installation. This wire was enclosed in 3/4-inch electrical conduit as outlined in the manufacturer's instructions. The 120-volt, 60-cycle, alternating-current power input to the meter was enclosed as recommended by the manufacturer in a separate conduit. The converter, recorder, and digital counter were mounted on a wooden panel about 4 feet away from the flowmeter, Figure 3.

Volumetric Calibration Tank

The laboratory calibration equipment includes two volumetric tanks of 678 cubic feet (5,071.8 gallons) (19.2 cubic meters) and 88 cubic feet (658.3 gallons) (2.53 cubic meters), a pneumatically operated swing spout for diverting the flow into or out of a tank, and an electronic timer, Figure 4. Volumes of both the large and small tanks have been determined for various water temperatures using an independent pipette tank. The timer, measuring time to the nearest 1/100 second, is started and stopped automatically by motion of the swing spout. The motion of the swing spout is manually controlled when the volumetric tank level reaches a depth sufficient for a hook gage measurement. The tank volume and time are used to compute the average rate of flow. The small volumetric tank was used for discharges up to about 300 gpm (0.67 cfs) (18.9 l/s) through the flowmeter. The large tank for discharges of 300 to 1,320 gpm.

The electronic timer was used also for timing the digital counter (volume totalizer of the magnetic meter). Signals from the converter to the digital counter were interrupted with a magnetic relay. The relay was activated by a manual switch at the calibration tank. Thus, by starting and stopping the digital counter in the same period as the timer, the volume of water in the calibration tank could be compared to the volume totalized by the meter.

CALIBRATION PROCEDURE

Converter Zeroing Procedure

Before each days tests, water was passed through the flow tube for 10 to 15 minutes near maximum flow to remove bubbles or material that might have accumulated on the electrodes when the meter was not in use. The discharge was then stopped by closing the valves both upstream and downstream of the meter to keep the pipe and meter tube full of water. The velocity range (the zero adjust range of the meter) (A) Figure 2A, was set on the converter. The zero button was depressed and the indicator needle was positioned by the zero (null) control screw (screwdriver hole above zero set button, Figure 1B). The needle was positioned to approximately midscale within the zero band (30 to 70 percent) to read between 50 and 60 percent. The indicator was checked periodically during the tests to insure that the needle was within the allowable zero band.

Discharge Measurements

Valves in the laboratory piping system were checked for leakage prior to the meter tests to insure that no flow was lost or bypassed the meter. For each discharge measurement the flow rate through the meter was adjusted using either the upstream or the downstream valve. The system was stabilized for 2 or 3 minutes with the flow bypassing the volumetric calibration tank. The flow was then diverted into either the large or small calibration tank, moving the swing spout started the electronic timer. The digital counter was started simultaneously with the timer. When the calibration tank was sufficiently full, the flow was diverted to the bypass. Again moving the swing spout automaticallly stopped the electric timer. The digital counter was switched off at the same time. The strip chart recorder was switched on at the beginning of each measurement to record the steadiness of the flow.

Water surface elevations in the calibration tank were read with a hook gage from a still water surface. The total volume was determined from the hook gage reading, the measured water temperature and calibration curves for the tank. Average discharges were computed by dividing the total volume of water in the tank by the time interval from the electronic timer.

The total volume of flow in gallons indicated by the meter was the product of the digital counter reading and a pulse factor corresponding to the velocity setting on the converter. The pulse factor for each velocity setting was supplied by the manufacturer as follows: 5 fps velocity setting, pulse factor = 0.183; 15 fps velocity setting, pulse factor = 0.550; 30 fps velocity setting, pulse factor = 1.100. The volume in gallons computed from the totalizer compared satisfactorily to that measured in the calibration tank.

The total volume in gallons divided by the time in minutes from the electronic timer gave the meter indicated average discharge in gallons per minute. To determine the discharge indicated by the recorder, the same pulse factors were applied to the chart reading.

Measurement Series

In the first series of measurement, the upstream valve was fully opened and the discharge was controlled using the valve located 15 diameters downstream. Discharges from 10 to 100 percent of maximum flow for each subrange were measured for a total discharge range of 22 to 1,320 gpm. About 20 runs were made for each subrange for a total of 60 runs. Three discharge measurements for discharge control by the downstream valve were checked after the meter had been installed for about 4 months.

The effect on the meter accuracy of setting the zero of the converter near the upper and lower limits was studied, in the second series of measurements. The upper and lower limits of the zero setting of the converter under no-flow conditions are 70 percent, and 30 percent according to the limit lines on the converter meter. The converter was adjusted to a 30 percent reading and test discharges were measured at the lower and upper ends of each velocity subrange, i.e., 22 and 220 gpm of the 22 to 220 gpm range. The same test discharges were then measured for 70 percent meter reading on the converter. Twenty-eight measurements were made in Series 2 with the upstream valve fully open.

For Series 3 the valve downstream of the meter was fully opened and flow was controlled using the gate valve located 15 diameters upstream of the meter. The discharges were measured to determine whether or not the flow from a partially opened valve affected the meter accuracy. Thirty-five discharges were measured in covering the three velocity subranges.

The upstream valve was installed at the inlet of the meter to control the flow for Series 4, Figure 3B. Thirty-three discharges were measured in the series. About 2 months after the initial series, four discharges were measured in the 130 to 1,320 gpm range. These four measurements were made to check the converter after a factory repair. The measurements showed that the converter had been repaired and the flowmeter was again indicating the true discharge.

DISCUSSION OF RESULTS

Accuracy of the magnetic flowmeter for measuring discharge was computed in two forms: as a percent of the rate of flow and as a percent of the maximum discharge for the velocity subrange.

$$\text{Accuracy (rate of flow)} = \frac{(Qm - Qv)}{(Qv)} \times 100 \text{ in percent}$$

$$\text{Accuracy (maximum flow for range)} = \frac{(Qm - Qv)}{(Qm(max))} \times 100 \text{ in percent}$$

where:

Qm = meter indicated discharge

Qv = volumetric tank measured discharge

Qm(max) = maximum meter indicated discharge for converter reading of 100 percent (220, 660, and 1,320 gpm)

A meter having a warranted accuracy of plus or minus 1 percent of rate can measure flow to a greater precision than one warranted to plus or minus 1 percent of full scale. For example:

Percent of flow rate

Full scale--220 gpm

Error at full scale--220 x 0.01 = ± 2.2 gpm

Rate of 10 percent of full scale 220 x 0.1 = 22 gpm

Error at rate 22 x 0.01 = ± 0.22 gpm or 1 percent

Percent of full scale

Error at full scale 220 x 0.01 = 2.2 gpm

Rate at 10 percent of full scale 220 x 0.1 = 22 gpm

Error at rate (possible) 2.2/22 x 100 = ± 10 percent

Test Series 1

Figure 5 shows the accuracy of the meter for measuring discharge in an installation where the meter was essentially unaffected by flow disturbances. The graphs show the accuracy of the meter in terms of the percent of the rate of flow within the range and the accuracy in percent of the maximum discharge of the range. The meter accuracy was within plus or minus 1 percent of full scale for each of the three subranges. The meter accuracy was plus or minus 1 percent of rate except for the lower end (20 percent of range or less) of each of the velocity ranges. In practical use the meter need not be operated at the low end of a velocity range except for the 0.5 to 5 fps range because the ranges overlap.

Test Series 2

Discharges were measured for the upper and lower end of each velocity range for the converter zero settings of 30 and 70 percent, Figure 6. The meter accuracy is impaired when the converter is operated near the limits of the allowable zero band. At the low end of the 0.5 to 5 fps velocity range the meter reads as much as 9.5 percent high for a 30 percent zero setting and 1.5 percent high for the 70 percent zero setting, Figure 6A. For the 1.5 to 15 fps and 3 to 30 fps velocity range the meter reads about 2.5 percent high at the low end of the velocity range for a 30 percent zero setting and about 1 percent high for the 70 percent zero setting.

Figure 6B shows the effect of the zero setting or meter accuracy expressed as percent of maximum discharge for the velocity range. The accuracy of the meter was plus or minus 1 percent of maximum flow or better both for either the 30 and 70 percent zero setting of the converter. The test series showed that meter accuracy in the lower discharge range is effected more by a zero shift than in the middle and upper ranges. A shift in zero toward the lower end of the zero band (30 percent) impairs the accuracy more than a shift toward the higher end of the zero band.

Test Series 3

The accuracy of the meter with a flow control 15 diameters upstream of the meter was not significantly different from that with the downstream flow control, Figure 7. The graphs show the accuracy of the meter in terms of the percent of rate of flow within the range and the accuracy in percent of the maximum discharge of the range. The velocity disturbance caused by a gate valve 15 diameters upstream does not appreciably affect the meter accuracy. The meter accuracy is about plus or minus 1 percent or better of rate except at the lower end of each velocity range.

Test Series 4

The electrodes of the meter were 15.6 inches (39.7 cm) downstream of the center of the leaf when the valve was installed at the inlet to the meter, Figure 3B. The relatively poor accuracy of the meter, Figure 8, for this installation was caused by the valve disturbance of the velocity distribution. When the valve was fully opened, the leaf did not obstruct the flow and the accuracy approached that obtained for downstream valve control. For the valve fully open (1,320-gpm flow) the meter indicated a discharge of 0.4 percent larger than the volumetric tank, Figure 8C. Using the downstream valve for control, the volumetric tank and meter measured the same discharge, Figure 5C.

The accuracy of the meter appears to be a function of the valve leaf position but was not a steadily increasing or decreasing function of valve opening. At certain valve openings the electrodes may be in a region of higher velocity than the average velocity. The result would be the meter indicating a higher than actual discharge. The accuracy measurements, Figure 8, show that a meter installation with a partially opened valve immediately upstream is not desirable.

Zero Control

The zeroing procedure of the secondary or readout system as outlined in the manufacturer's instructions was followed for each of the series. The zero shift was minimal for Series 1, 2, and 3. During the latter part of Series 4, the zero shift became excessive. The indicator needle of the converter drifted outside of the allowable zero band. Different zeroing procedures were followed as outlined by manufacturer's representatives but it was not always possible to zero the system. The converter was sent to the factory for service and was returned with additional instructions for zeroing the system.

Four discharges were measured by hydraulic laboratory personnel and manufacturer's representatives after the converter was put back in operation. The test discharges confirmed the results of Series 4, Figure 8, and showed no apparent effect of zero shift. The system could be zeroed after the factory service and was still functioning 1 month later. However, the fact that the converter failed to zero properly after only 1 month of operation in a laboratory environment may raise a question as to the reliability of the meter under field conditions.

CONCLUSIONS

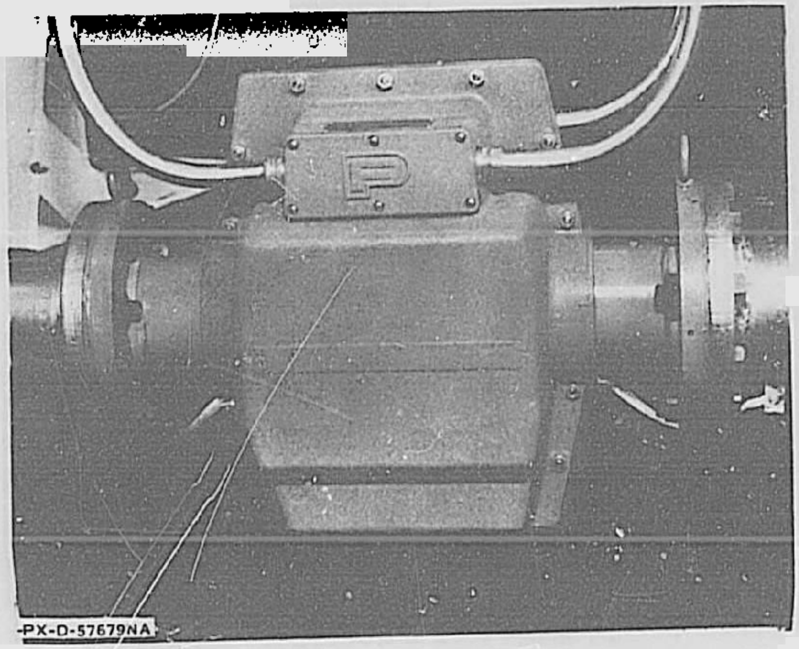
1. The Fischer-Porter magnetic flowmeter system tested has a discharge range of 22 to 1,320 gpm (.049 to 2.94 cfs) (1.4 to 83.2 liters per second). The total discharge range is divided into three subranges, 22 to 220 gpm, 66 to 660 gpm and 132 to 1,320 gpm.

2. For a normal installation the meter accuracy is within plus or minus 1 percent of maximum discharge for each subrange and is within plus or minus 1 percent of the rate indicated for the upper 80 percent of each discharge range. At the minimum discharge for each range the meter indicates from 1 to 2 percent higher than actual discharge.

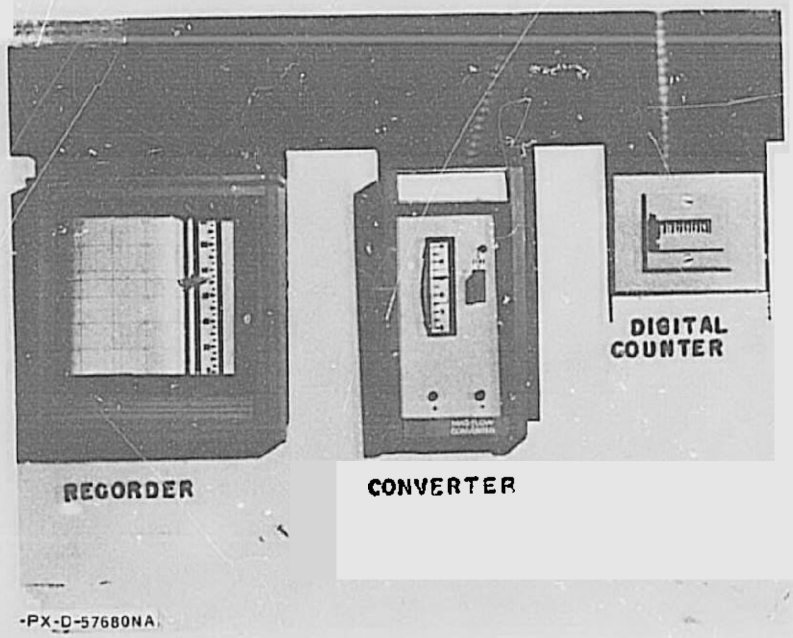
3. An installation with the control valve at the meter inlet is not desirable and can cause inaccuracies in discharge measurement of 4 percent or more.

4. During the zeroing procedure the indicator needle on the converter should be set in the center of the zero band or at a reading of about 50 percent to obtain the best accuracy.

5. The failure of the converter to function after 1 month's operation in the laboratory may be an indication of less than adequate reliability in a field installation.



A. 4-inch Fischer-Porter magnetic flowmeter primary.

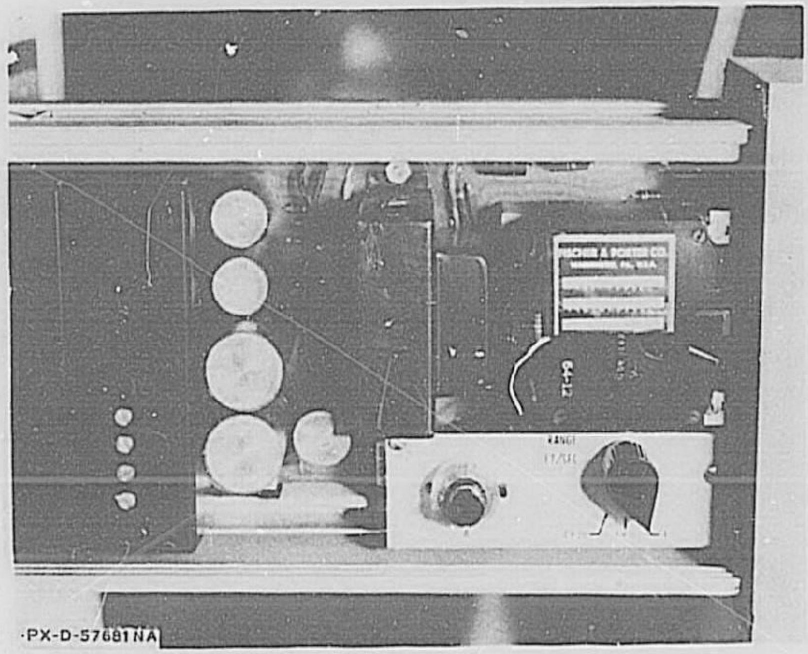


B. Secondary or readout system for magnetic flowmeter.

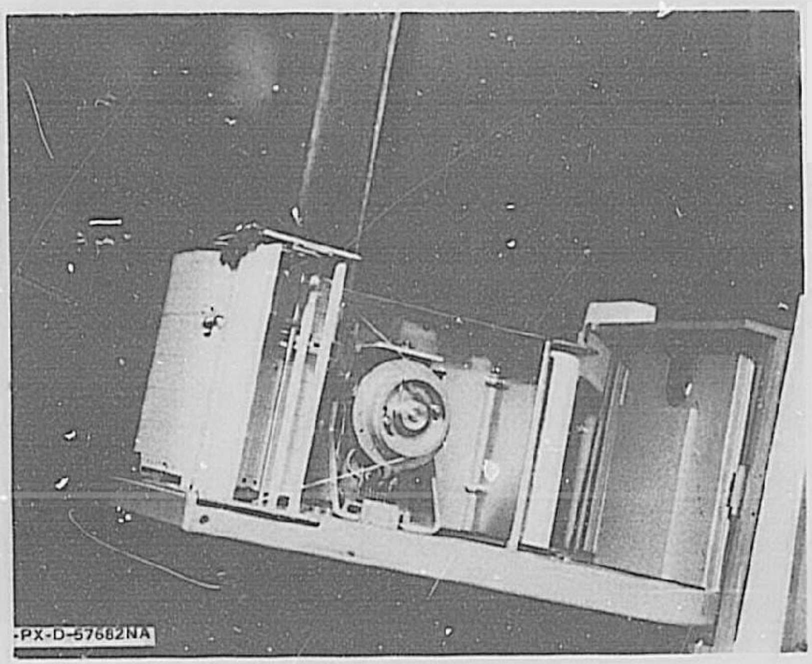
MAGNETIC FLOWMETER STUDY

Four-inch Fischer-Porter Magnetic Flowmeter System

Figure 2
Report No. Hyd-574



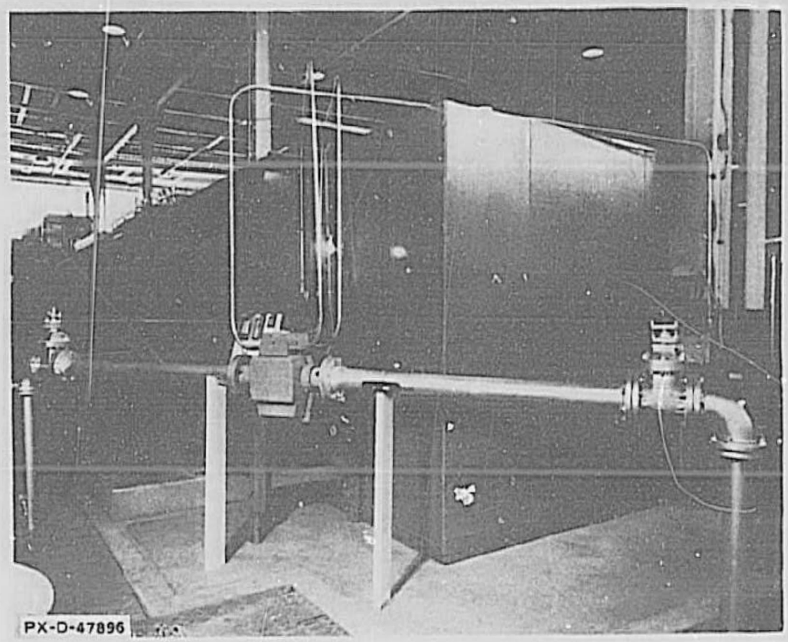
A. Magnetic flowmeter converter showing velocity range selector.



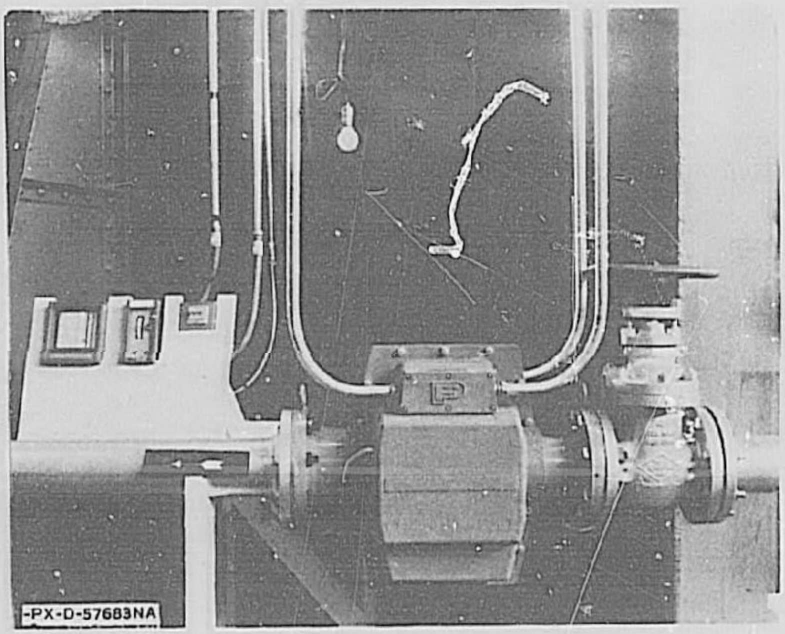
B. Single pen strip chart recorder.

MAGNETIC FLOWMETER STUDY

Magnetic Flowmeter Converter and Recorder



A. Laboratory meter installation with valve 15 diameters upstream and downstream.

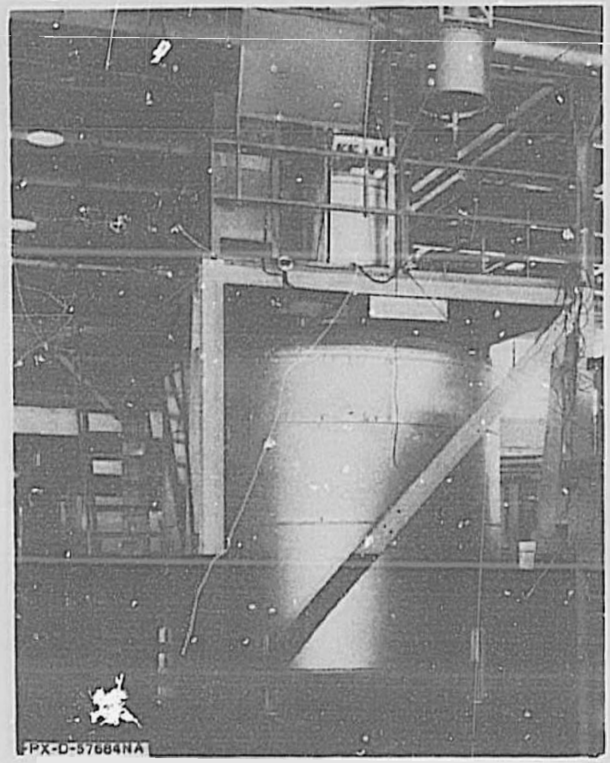


B. Installation with valve placed at meter inlet.

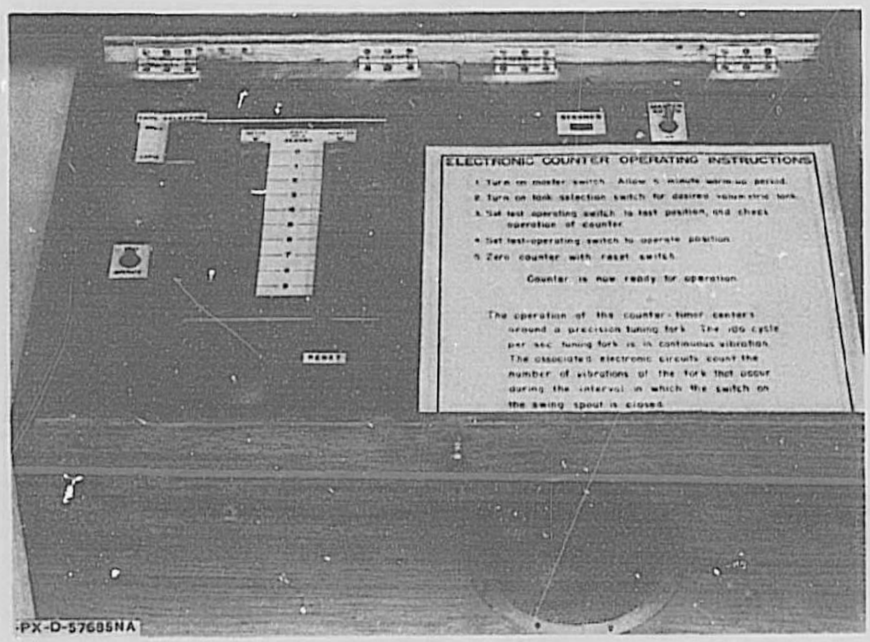
MAGNETIC FLOWMETER STUDY

Laboratory Installation of Magnetic Flowmeter

Figure 4
Report No. Hyd-574



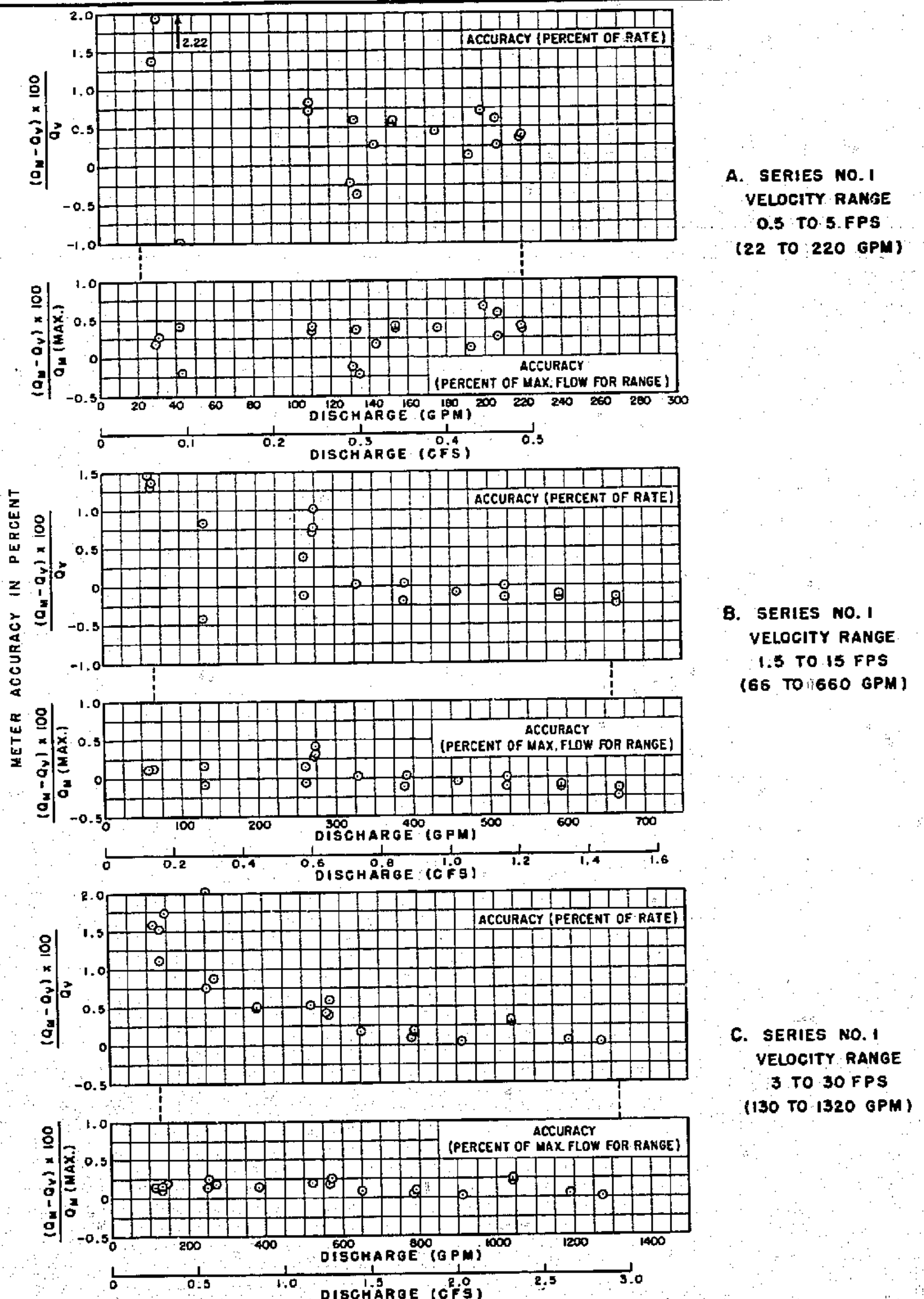
A. Laboratory volumetric calibration tank.



B. Electronic timer for volumetric calibration facility.

MAGNETIC FLOWMETER STUDY

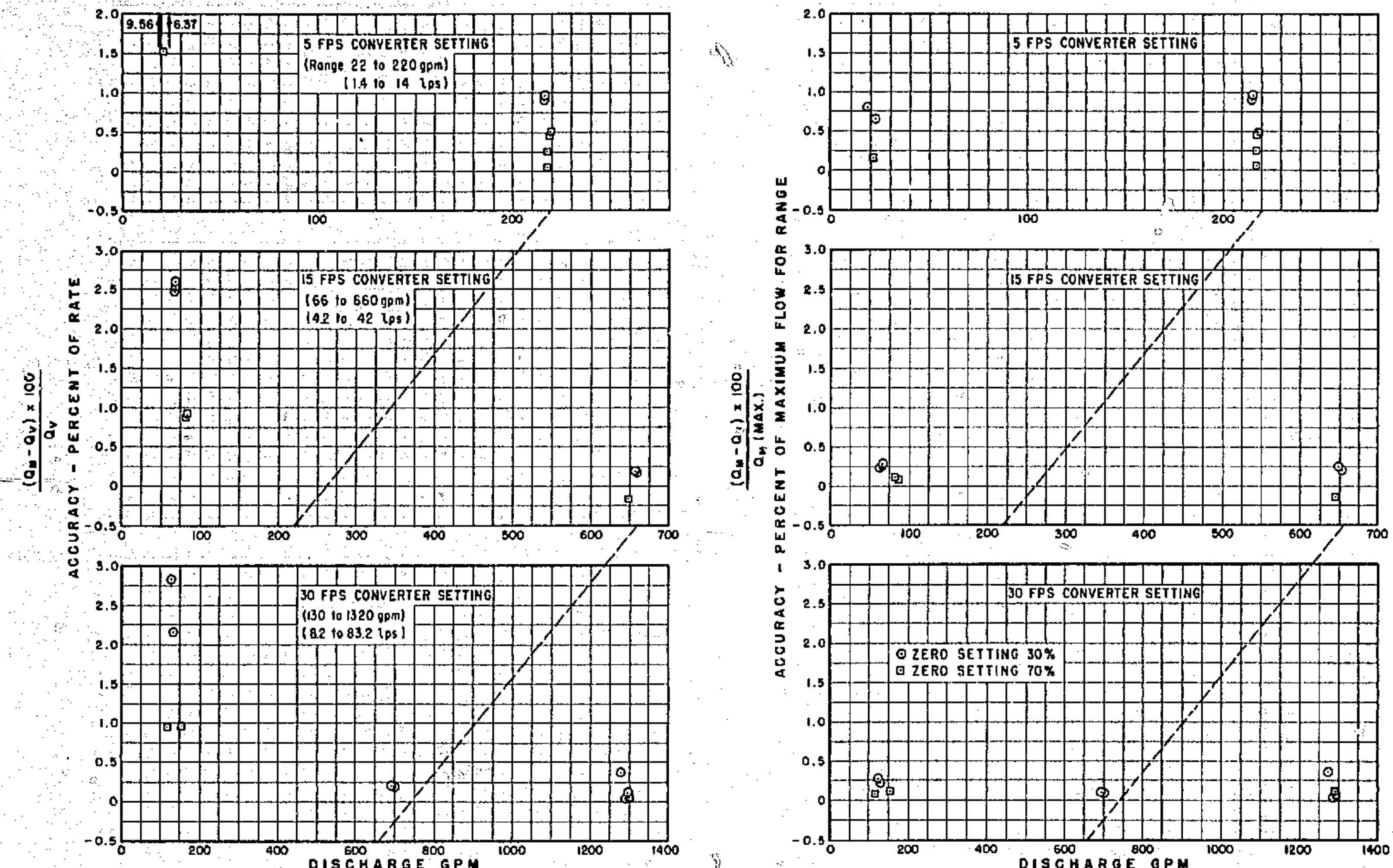
Laboratory Volumetric Calibration Facilities



MAGNETIC FLOWMETER STUDY

METER ACCURACY – DISCHARGE CONTROL 15 PIPE DIAMETERS DOWNSTREAM FROM METER

FIGURE 6
REPORT HYD-574

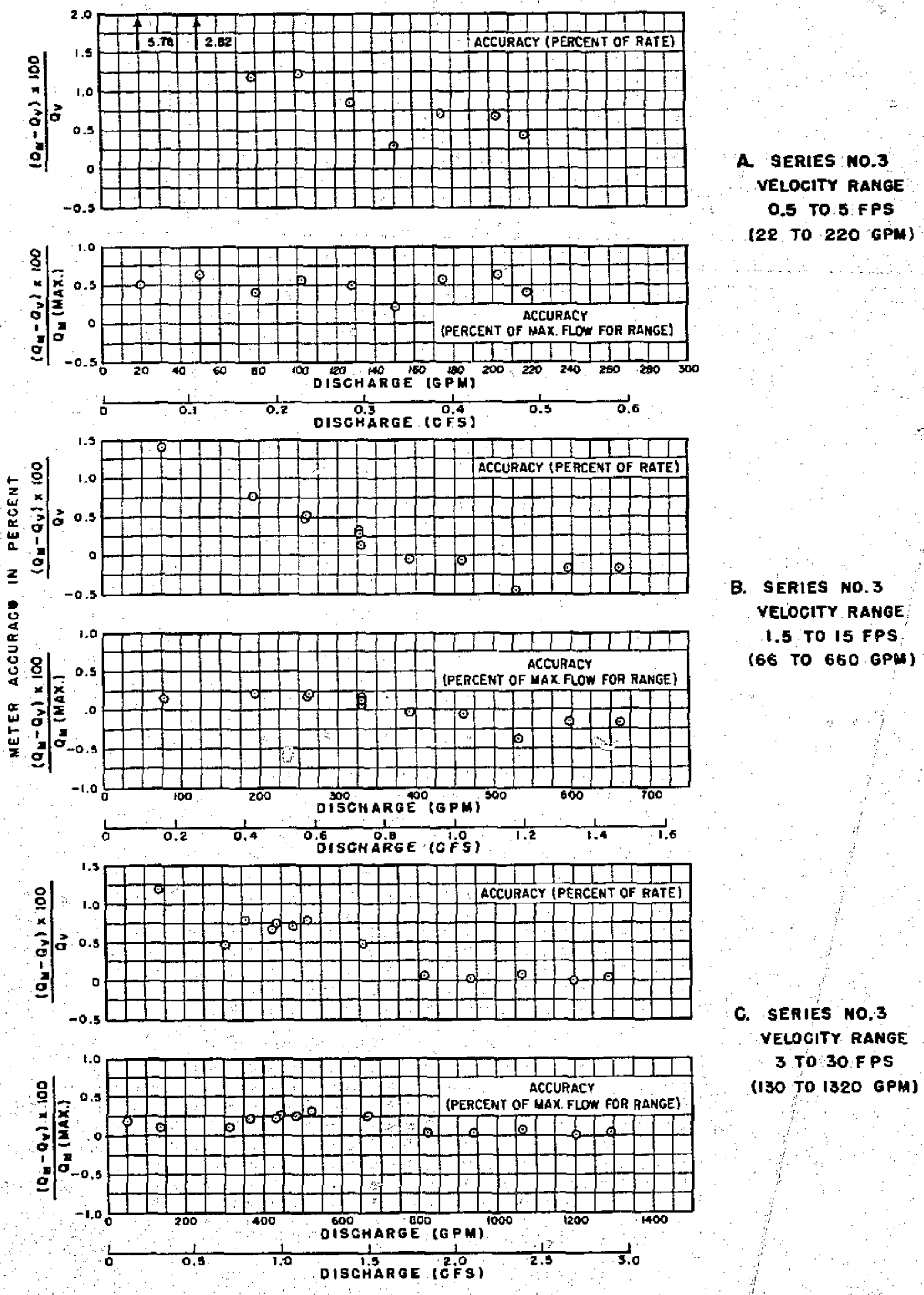


A. METER ACCURACY PERCENT OF RATE

B. METER ACCURACY PERCENT OF FULL SCALE FOR RANGE

MAGNETIC FLOWMETER STUDY

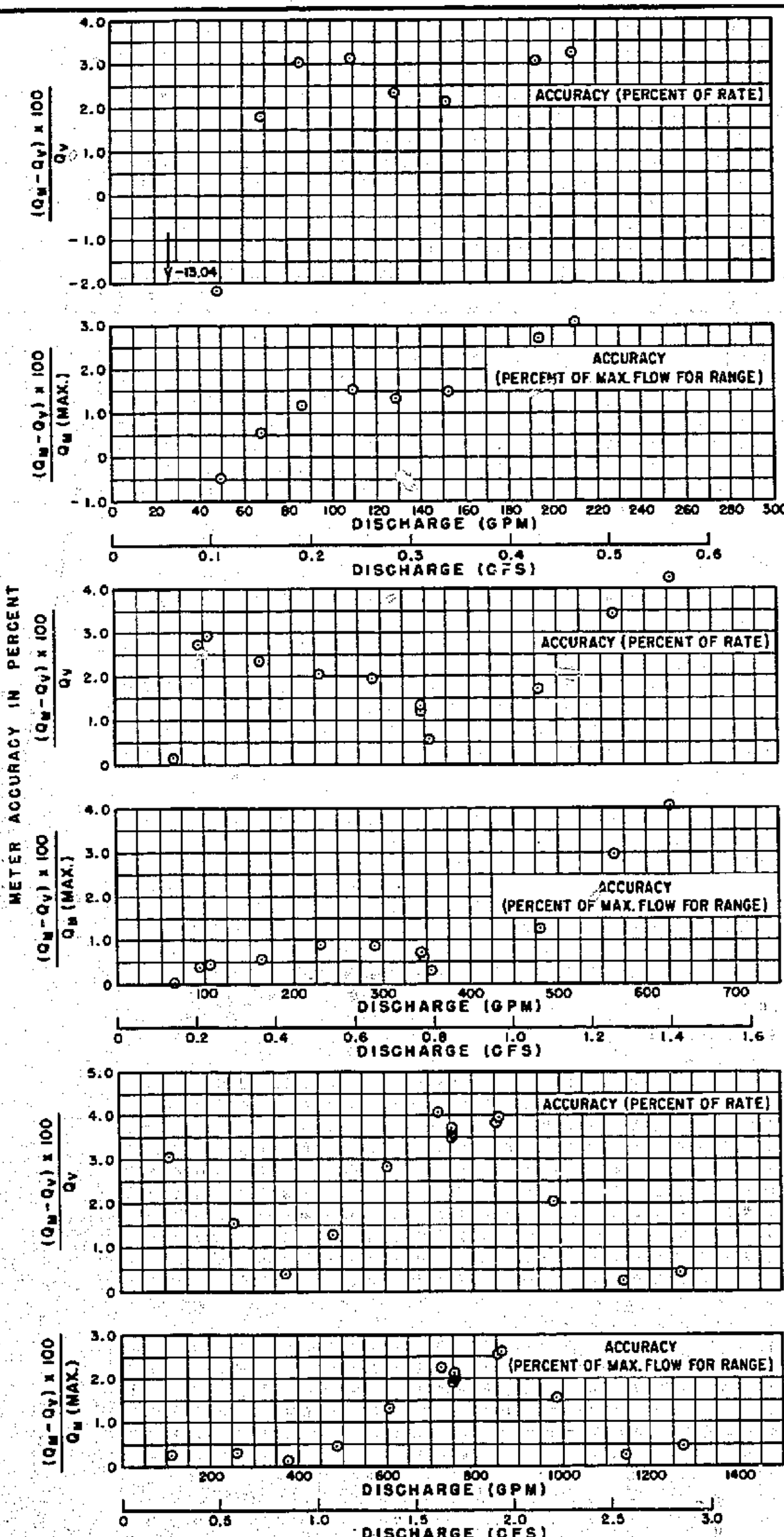
METER ACCURACY - EFFECT OF CONVERTER ZERO CONTROL



MAGNETIC FLOWMETER STUDY

METER ACCURACY - DISCHARGE CONTROL 15 PIPE DIAMETERS UPSTREAM FROM METER

FIGURE 8
REPORT HYD-574



A. SERIES NO. 4
VELOCITY RANGE
0.5 TO 5 FPS
(22 TO 220 GPM)

B. SERIES NO. 4
VELOCITY RANGE
1.5 TO 15 FPS
(66 TO 660 GPM)

C. SERIES NO. 4
VELOCITY RANGE
3 TO 30 FPS
(130 TO 1320 GPM)

MAGNETIC FLOWMETER STUDY

METER ACCURACY - DISCHARGE CONTROL VALVE AT INLET TO METER

GPO 835-788

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03*	Square centimeters
	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	946.358*	Cubic centimeters
	0.946331*	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.092903*	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

GPO 835-159

ABSTRACT

A 4-in. magnetic flowmeter was studied to determine its operating characteristics, accuracy, and general performance. The discharge range of the meter was 22 to 1320 gpm (0.05 to 2.94 cfs). The range is made adjustable by the manufacturer into 3 subranges of 22 to 220, 66 to 660, and 130 to 1320 gpm. At the minimum discharges for each subrange, the meter read from 1 to 2% high. An accuracy of plus or minus 1% of the rate of flow was obtained for about the upper 80% of each subrange. Control of the flow with a gate valve located 15 dia upstream or downstream from the meter had negligible effect on the meter accuracy. Controlling the flow with a valve at the inlet to the meter caused the indicated discharge to be 4% higher than the actual discharge. Operation of the meter was generally satisfactory, but a failure of an electronic component after 1 month's use raised a question on system reliability.

ABSTRACT

A 4-in. magnetic flowmeter was studied to determine its operating characteristics, accuracy, and general performance. The discharge range of the meter was 22 to 1320 gpm (0.05 to 2.94 cfs). The range is made adjustable by the manufacturer into 3 subranges of 22 to 220, 66 to 660, and 130 to 1320 gpm. At the minimum discharges for each subrange, the meter read from 1 to 2% high. An accuracy of plus or minus 1% of the rate of flow was obtained for about the upper 80% of each subrange. Control of the flow with a gate valve located 15 dia upstream or downstream from the meter had negligible effect on the meter accuracy. Controlling the flow with a valve at the inlet to the meter caused the indicated discharge to be 4% higher than the actual discharge. Operation of the meter was generally satisfactory, but a failure of an electronic component after 1 month's use raised a question on system reliability.

ABSTRACT

A 4-in. magnetic flowmeter was studied to determine its operating characteristics, accuracy, and general performance. The discharge range of the meter was 22 to 1320 gpm (0.05 to 2.94 cfs). The range is made adjustable by the manufacturer into 3 subranges of 22 to 220, 66 to 660, and 130 to 1320 gpm. At the minimum discharges for each subrange, the meter read from 1 to 2% high. An accuracy of plus or minus 1% of the rate of flow was obtained for about the upper 80% of each subrange. Control of the flow with a gate valve located 15 dia upstream or downstream from the meter had negligible effect on the meter accuracy. Controlling the flow with a valve at the inlet to the meter caused the indicated discharge to be 4% higher than the actual discharge. Operation of the meter was generally satisfactory, but a failure of an electronic component after 1 month's use raised a question on system reliability.

ABSTRACT

A 4-in. magnetic flowmeter was studied to determine its operating characteristics, accuracy, and general performance. The discharge range of the meter was 22 to 1320 gpm (0.05 to 2.94 cfs). The range is made adjustable by the manufacturer into 3 subranges of 22 to 220, 66 to 660, and 130 to 1320 gpm. At the minimum discharges for each subrange, the meter read from 1 to 2% high. An accuracy of plus or minus 1% of the rate of flow was obtained for about the upper 80% of each subrange. Control of the flow with a gate valve located 15 dia upstream or downstream from the meter had negligible effect on the meter accuracy. Controlling the flow with a valve at the inlet to the meter caused the indicated discharge to be 4% higher than the actual discharge. Operation of the meter was generally satisfactory, but a failure of an electronic component after 1 month's use raised a question on system reliability.

Hyd-574
Brockway, C E and Schuster, J C
INVESTIGATION OF A 4-INCH MAGNETIC FLOWMETER
USBR Lab Rept Hyd-574, Hyd Br, May 1967. Bureau of Reclamation, Denver,
10 pp, 8 fig, 2 tab

DESCRIPTORS-- magnetic fields/ electric potential/ hydraulics/ meters/ *water meters/ *flow meters/ closed conduits/ pipelines/ *water measurement/ laboratory tests/ calibrations/ performance tests
IDENTIFIERS-- Fischer-Porter flow meter/ product evaluation/ magnetic flow meters
FOR U S GOVERNMENT USE ONLY

Hyd-574
Brockway, C E and Schuster, J C
INVESTIGATION OF A 4-INCH MAGNETIC FLOWMETER
USBR Lab Rept Hyd-574, Hyd Br, May 1967. Bureau of Reclamation, Denver,
10 pp, 8 fig, 2 tab

DESCRIPTORS-- magnetic fields/ electric potential/ hydraulics/ meters/ *water meters/ *flow meters/ closed conduits/ pipelines/ *water measurement/ laboratory tests/ calibrations/ performance tests
IDENTIFIERS-- Fischer-Porter flow meter/ product evaluation/ magnetic flow meters
FOR U S GOVERNMENT USE ONLY

Hyd-574
Brockway, C E and Schuster, J C
INVESTIGATION OF A 4-INCH MAGNETIC FLOWMETER
USBR Lab Rept Hyd-574, Hyd Br, May 1967. Bureau of Reclamation, Denver,
10 pp, 8 fig, 2 tab

DESCRIPTORS-- magnetic fields/ electric potential/ hydraulics/ meters/ *water meters/ *flow meters/ closed conduits/ pipelines/ *water measurement/ laboratory tests/ calibrations/ performance tests
IDENTIFIERS-- Fischer-Porter flow meter/ product evaluation/ magnetic flow meters
FOR U S GOVERNMENT USE ONLY

Hyd-574
Brockway, C E and Schuster, J C
INVESTIGATION OF A 4-INCH MAGNETIC FLOWMETER
USBR Lab Rept Hyd-574, Hyd Br, May 1967. Bureau of Reclamation, Denver,
10 pp, 8 fig, 2 tab

DESCRIPTORS-- magnetic fields/ electric potential/ hydraulics/ meters/ *water meters/ *flow meters/ closed conduits/ pipelines/ *water measurement/ laboratory tests/ calibrations/ performance tests
IDENTIFIERS-- Fischer-Porter flow meter/ product evaluation/ magnetic flow meters
FOR U S GOVERNMENT USE ONLY