

Water Meters— Selection, Installation, Testing, and Maintenance

MANUAL OF WATER SUPPLY PRACTICES

M6

Fifth Edition



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Addendum to
AWWA Manual M6,
Water Meters—Selection, Installation, Testing,
and Maintenance, Fifth Edition
(November 2018)

Purpose

The 2018 Addendum to AWWA Manual M6, Water Meters—Selection, Installation, Testing, and Maintenance, fifth edition, provides guidance to users on testing procedures and related topics for meters conforming to standard ANSI/AWWA C715-18 Cold-Water Meters—Electromagnetic and Ultrasonic Type, for Revenue Applications. This standard was approved by the AWWA Standards Committee on Water Meters on February 19, 2018, approved by the AWWA Board of Directors on June 9, 2018, and made effective on October 1, 2018.

The 2018 Addendum is considered a part of AWWA Manual M6 wherever the manual is referenced by AWWA water meter standards or other documents.

The current edition of AWWA Manual M6, the fifth edition, was published in 2012. The AWWA Water Meter Standards Committee believes that the 2018 Addendum to the manual fills an immediate need by water utilities for up-to-date meter testing procedures and that it was important for this information to be published in the interim, as work is continuing on the sixth edition of the manual.

Background

Historically, AWWA Manual M6 has served as a guide to best practices for water meters, as a companion document to the AWWA water meter standards. From a practical standpoint, the manual is often used as a reference tool by utilities in their meter shops for determining and executing the proper testing procedures for the various meter types and sizes.

As the family of AWWA water meter standards has expanded over the years to include new meter types, AWWA Manual M6 has also grown to include information on these new meters. The common practice has been that Manual M6 includes information on the meter types for which an AWWA standard exists. The fifth edition of the manual, for example, was expanded in 2012 to include information on singlejet-type (ANSI/AWWA C712) and fluidic oscillator-type (ANSI/AWWA C713) meters. The sixth edition will include more information on electromagnetic- and ultrasonic-type (ANSI/AWWA C715) meters, as well as meters for residential fire sprinkler systems in one- and two-family dwellings and manufactured homes (ANSI/AWWA C714).

Testing Procedures

Table 5-3 includes recommended data for testing cold-water meters by the volumetric method, using volumetric tanks, or by the gravimetric method, using weight scales. This data may also be used for testing cold-water meters against a master or reference meter that has a known calibration curve. Accuracy standards for new meters are contained in the latest editions of standards ANSI/AWWA C700, C701, C702, C703, C704, C708, C710, C712, C713, C714, and C715. The modified Table 5-3 issued in this addendum reflects the latest accuracy standards from these AWWA standards.

The following listing provides additional guidance on meter testing, beyond the modifications made in Table 5-3.

1. In testing meters to validate their accuracy (either prior to deployment or after some time in service), note that the testing procedures for electronic meters, may be different from those meters previously placed in service. The manufacturer's recommended testing procedures should be followed. Ignoring these recommendations can invalidate the accuracy results.
2. Electronic meters do not have moving parts and, therefore, are not subject to the same wear and tear as mechanical meters. Although AWWA standards for mechanical water meters provide recommended testing frequencies in the appendix of each standard, recommended testing frequencies are not provided in the appendix of ANSI/AWWA C715. Water quality and other local conditions may affect the performance of electronic meters over time. To assess these site-specific effects, the utility may choose to verify the accuracy of electronic meters at the recommended test frequencies provided in AWWA standards for mechanical meters, until the utility establishes its own criteria based on data collected on its operational experience and local conditions.
3. Some of the smaller electronic meters have minimum rate accuracy requirements at lower flow rates than any of the rates given in other AWWA meter standards (i.e., flow rates lower than 0.25 gpm). In other instances, the minimum rate flow rates of electronic meters may be lower than those of the mechanical meters previously deployed by the utility, for any given line size. Accuracy at these lower flow rates, therefore, might be more difficult to test and verify on the existing utility's meter test bench equipment. Gravimetric systems might provide more sensitivity than volumetric systems. In all cases, the testing equipment must be maintained properly, calibrated periodically, and certified to ensure it is working properly.
4. As discussed in item #3, a utility's testing equipment may not be capable of testing electronic meters reliably at the lower flow rates (particularly for flow rates even lower than the minimums given in ANSI/AWWA C715, if part of the manufacturer's warranted accuracy claims). If this is the case, an independent third-party service company with certified and calibrated equipment along with sound testing protocols may need to be engaged to verify accuracy. As provided in one of the footnotes for the modified Table 5-3 in this addendum, a utility may alternatively increase the minimum test rate flow to stay within the capability of their equipment, while holding the electronic meters to their tighter accuracy requirement at these somewhat higher flow rates. Utilities may also wish to use these somewhat higher flow rates when there are test time constraints.
5. Historically, Table 5-3 has included some caveats in test quantity recommendations, relative to the footnote that has called for "not less than 3 min running." This has been most notable for some of the maximum rate test quantities, which would result in test run times well below three minutes in length. This ambiguity recognizes limitations in the number and size of test tanks with which the utility may be equipped. The footnote further provides that, for reduced test quantities, "the resultant increase in total test

uncertainties and errors need to be recognized.” While mechanical water meters may have been able to accommodate those test quantities in Table 5-3 that result in test times of less than three minutes, this may not be the case for some electronic meters. A special test mode—temporarily increasing the sampling rate for the meter—may be available for some electronic meter designs, to mitigate the test uncertainties associated with test times shorter than three minutes.

6. Table 5-3 provides recommended test flow rates. These recommendations are based, in part, on the observation that all meters of the same type (all positive displacement meters, all turbine meters, and so on) will exhibit the same or similar characteristic accuracy curves. This may not be a valid observation for electronic meters, for which distinct calibration algorithms may be in use. As a result, alternate or additional flow test rates may be considered. These would be especially relevant for flow rates given in the manufacturer’s performance claims that significantly exceed the ranges established in AWWA water meter standards.
7. Electromagnetic- and ultrasonic-type electronic meters are inferential in nature, measuring water velocities and inferring volumetric flows based on these velocities. (Many mechanical flow meters are also inferential in nature.) Inferential meters can be susceptible to flow profile disturbances, and to “noisy” flow delivery systems (e.g., pressure pulsations). Care should be taken to ensure that utility test stands do not introduce disturbances or noise at levels that are not representative of those that occur in actual field installations.

For the sixth edition of this manual, expanded information on several aspects of meter testing will be provided; these will include test uncertainties related to testing equipment, test uncertainties related to procedures and practices, and evaluation of accuracy results for meters pulled from service in the field. If users of this manual have any comments, questions, or suggestions regarding this manual, they can contact the AWWA Standards group at standards@awwa.org.

For this 2018 Manual M6 addendum, Table 5-3 of Manual M6, fifth edition (2012) is replaced with the following Table 5-3:

Table 5-3 Test requirements for new, rebuilt, and repaired cold-water meters*
Displacement Meters (ANSI/AWWA C700 and C710)

Size	Maximum Rate (All Meters)				Intermediate Rate (All Meters)				Minimum Rate (New and Rebuilt)				Minimum (Repaired)
	Flow Rate†	Test Quantity††		Accuracy Limits	Flow Rate**	Test Quantity††		Accuracy Limits	Flow Rate	Test Quantity††		Accuracy Limits	Minimum (Repaired)
		gal	ft³			gal	ft³			gal	ft³		
in.	<i>gpm</i>			<i>percent</i>				<i>percent</i>				<i>percent</i>	<i>percent (min)</i>
1/2	8	100	10	98.5–101.5	2	10	1	98.5–101.5	1/4	10	1	95–101	90
1/2 x 3/4	8	100	10	98.5–101.5	2	10	1	98.5–101.5	1/4	10	1	95–101	90
5/8	15	100	10	98.5–101.5	2	10	1	98.5–101.5	1/4	10	1	95–101	90
5/8 x 3/4	15	100	10	98.5–101.5	2	10	1	98.5–101.5	1/4	10	1	95–101	90
3/4	25	100	10	98.5–101.5	3	10	1	98.5–101.5	1/2	10	1	95–101	90
1	40	100	10	98.5–101.5	4	10	1	98.5–101.5	3/4	10	1	95–101	90
1½	50	100	10	98.5–101.5	8	100	10	98.5–101.5	1½	100	10	95–101	90
2	100	100	10	98.5–101.5	15	100	10	98.5–101.5	2	100	10	95–101	90

Multijet Meters (ANSI/AWWA C708)

Size	Maximum Rate (All Meters)				Intermediate Rate (All Meters)				Minimum Rate (New and Rebuilt)				Minimum (Repaired)
	Flow Rate†	Test Quantity††		Accuracy Limits	Flow Rate**	Test Quantity††		Accuracy Limits	Flow Rate	Test Quantity††		Accuracy Limits	
		gal	ft³			percent	gal			ft³	percent		
in.	<i>gpm</i>			<i>percent</i>				<i>gpm</i>				<i>percent</i>	<i>percent (min)</i>
5/8	15	100	10	98.5–101.5	1	10	1	98.5–101.5	1/4	10	1	97–103	90
5/8 x 3/4	15	100	10	98.5–101.5	1	10	1	98.5–101.5	1/4	10	1	97–103	90
3/4	25	100	10	98.5–101.5	2	10	1	98.5–101.5	1/2	10	1	97–103	90
1	35	100	10	98.5–101.5	3	10	1	98.5–101.5	3/4	10	1	97–103	90
1½	70	100	10	98.5–101.5	5	100	10	98.5–101.5	1½	100	10	97–103	90
2	100	100	10	98.5–101.5	8	100	10	98.5–101.5	2	100	10	97–103	90

Continued

Singlejet Meters (ANSI/AWWA C712)

Size	Maximum Rate (All Meters)			Intermediate Rate (All Meters)			Minimum Rate (New and Rebuilt)			Minimum (Repaired)			
	Flow Rate†	Test Quantity††		Accuracy Limits	Flow Rate**	Test Quantity††		Accuracy Limits	Flow Rate	Test Quantity††		Accuracy Limits	
		gal	ft³			gal	ft³			gal	ft³		gal
in.	gpm			percent				percent				percent (min)	
5/8	15	100	10	98.5–101.5	2	10	1	98.5–101.5	1/4	10	1	95–101.5	90
5/8 x 3/4	15	100	10	98.5–101.5	2	10	1	98.5–101.5	1/4	10	1	95–101.5	90
	25	100	10	98.5–101.5	3	10	1	98.5–101.5	1/2	10	1	95–101.5	90
1	40	100	10	98.5–101.5	4	10	1	98.5–101.5	3/4	10	1	95–101.5	90
1½	50	100	10	98.5–101.5	8	100	10	98.5–101.5	1/2	100	10	95–101.5	90
2	100	100	10	98.5–101.5	15	100	10	98.5–101.5	1/2	100	10	95–101.5	90
3	160	500	50	98.5–101.5	20	100	10	98.5–101.5	1/2	100	10	95–101.5	90
4	250	500	50	98.5–101.5	40	100	10	98.5–101.5	3/4	100	10	95–101.5	90
6	500	1,000	100	98.5–101.5	60	100	10	98.5–101.5	1½	100	10	95–101.5	90

Fluidic-Oscillator Meters (ANSI/AWWA C713)

Size	Maximum Rate (All Meters)			Intermediate Rate (All Meters)			Minimum Rate (New and Rebuilt)			Minimum (Repaired)		
	Flow Rate†	Test Quantity††	Accuracy Limits	Flow Rate**	Test Quantity††		Accuracy Limits	Flow Rate	Test Quantity††		Accuracy Limits	
					gal	ft³						gal
in.	<i>gpm</i>		<i>percent</i>	<i>gpm</i>	<i>gal</i>	<i>ft³</i>	<i>percent</i>	<i>gpm</i>	<i>gal</i>	<i>ft³</i>	<i>percent</i>	<i>percent (min)</i>
1/2	8	100	10	2	10	1	98.5–101.5	1/4	10	1	95–101.5	90
1/2 x 3/4	8	100	10	2	10	1	98.5–101.5	1/4	10	1	95–101.5	90
5/8	15	100	10	2	10	1	98.5–101.5	1/4	10	1	95–101.5	90
5/8 x 3/4	15	100	10	2	10	1	98.5–101.5	1/4	10	1	95–101.5	90
3/4	25	100	10	3	10	1	98.5–101.5	1/2	10	1	95–101.5	90
1	40	100	10	4	10	1	98.5–101.5	3/4	10	1	95–101.5	90
1½	50	100	10	8	100	10	98.5–101.5	1½	100	10	95–101.5	90
2	100	100	10	15	100	10	98.5–101.5	2	100	10	95–101.5	90

Continued

**Class I Turbine Meters,
Vertical-Shaft Type (ANSI/AWWA C701)**

Size	Maximum Rate (All Meters)			Intermediate Rate (All Meters)				Minimum Rate (New and Rebuilt)				Minimum (Repaired)
	Flow Rate†	Test Quantity††		Flow Rate**	Test Quantity††		Accuracy Limits	Flow Rate	Test Quantity††		Accuracy Limits	Accuracy Limits
		gal	ft³		gal	ft³			gal	ft³		
in.	gpm			gpm			percent	gpm			percent	percent (min)
3/4	30	100	10	3	10	1	98–102	1½	10	1	98–102	—
1	50	100	10	5	10	1	98–102	2	10	1	98–102	—
1½	100	500	50	10	100	10	98–102	3	100	10	98–102	—
2	160	500	50	16	100	10	98–102	4	100	10	98–102	—
3	350	1,000	100	35	100	10	98–102	6	100	10	98–102	—
4	600	1,500	200	60	100	10	98–102	8	100	10	98–102	—
6	1,250	4,000	500	125	1,000	100	98–102	15	1,000	100	98–102	—

**Class II Turbine Meters,
In-Line (High-Velocity) Type (ANSI/AWWA C701)**

Size	Maximum Rate (All Meters)			Intermediate Rate (All Meters)				Minimum Rate (New and Rebuilt)				Minimum (Repaired)
	Flow Rate†	Test Quantity††		Flow Rate**	Test Quantity††		Accuracy Limits	Flow Rate	Test Quantity††		Accuracy Limits	Accuracy Limits
		gal	ft³		gal	ft³			gal	ft³		
in.	gpm			gpm			percent	gpm			percent	percent (min)
1½	100	500	50				98.5–101.5	4	100	10	98.5–101.5	—
2	160	500	50				98.5–101.5	4	100	10	98.5–101.5	—
3	350	1,000	100				98.5–101.5	8	100	10	98.5–101.5	—
4	630	1,500	200				98.5–101.5	15	100	10	98.5–101.5	—
6	1,400	4,000	500				98.5–101.5	30	1,000	100	98.5–101.5	—
8	2,400	7,000	900				98.5–101.5	50	1,000	100	98.5–101.5	—
10	3,800	10,000	1,300				98.5–101.5	75	1,000	100	98.5–101.5	—
12	5,000	15,000	2,000				98.5–101.5	120	1,000	100	98.5–101.5	—
16	7,000	30,000	4,000				98.5–101.5	200	1,000	100	98.5–101.5	—
20	10,000	40,000	5,000				98.5–101.5	300	1,000	100	98.5–101.5	—

Continued

Propeller Meters (ANSI/AWWA C704)

Size	Maximum Rate (All Meters)			Intermediate Rate (All Meters)			Minimum Rate (New and Rebuilt)			Minimum (Repaired)
	Flow Rate† <i>gpm</i>	Test Quantity†† <i>gal</i>	Accuracy Limits <i>percent</i>	Flow Rate** <i>gpm</i>	Test Quantity†† <i>gal</i>	Accuracy Limits <i>percent</i>	Flow Rate <i>gpm</i>	Test Quantity†† <i>gal</i>	Accuracy Limits <i>percent</i>	
<i>in.</i>		<i>ft³</i>			<i>ft³</i>			<i>ft³</i>		<i>percent (min)</i>
2	100	300	40				45	200	25	98–102
3	250	800	100				80	200	25	98–102
4	500	1,500	200				85	250	30	98–102
6	1,200	2,500	300				160	500	60	98–102
8	1,500	3,000	400				190	500	60	98–102
10	2,000	4,000	500				260	500	60	98–102
12	2,800	6,000	800				275	750	100	98–102
14	3,750	8,000	1,000				350	1,000	130	98–102
16	4,750	10,000	1,300				450	1,500	200	98–102
18	5,625	12,000	1,600				550	2,000	250	98–102
20	6,875	15,000	2,000				650	2,500	300	98–102
24	10,000	20,000	2,500				1,000	4,000	500	98–102
30	15,000	30,000	4,000				1,600	6,000	800	98–102
36	20,000	40,000	5,000				2,400	7,500	1,000	98–102
42	28,000	40,000	5,000				2,800	10,000	1,300	98–102
48	35,000	50,000	6,000				3,500	12,500	1,500	98–102
54	45,000	60,000	8,000				5,000	16,000	2,000	98–102
60	60,000	70,000	9,000				6,000	20,000	2,500	98–102
66	75,000	80,000	11,000				7,500	25,000	3,000	98–102
72	90,000	90,000	12,000				9,000	28,000	3,500	98–102

Continued

Compound Meters (ANSI/AWWA C702)§

Size	Maximum Rate (All Meters)				Change Over Point (All Meters)			Minimum Rate (New and Rebuilt)			Minimum (Repaired)		
	Flow Rate†	Test Quantity††		Accuracy Limits	Flow Rate**	Test Quantity††		Accuracy Limits	Flow Rate	Test Quantity††		Accuracy Limits	
		gal	ft³			gal	ft³			gal	ft³		
in.	gpm			percent	gpm	gal	ft³	percent	gpm			percent	Accuracy Limits
				Class I								percent	percent (min)
				Class II									
2	160	400	50	97–103	98.5–101.5			90–103				95–101	90
3	320	1,000	100	97–103	98.5–101.5			90–103				95–101	90
4	500	1,500	200	97–103	98.5–101.5			90–103				95–101	90
6	1,000	3,000	400	97–103	98.5–101.5			90–103				95–101	90
8	1,600	4,000	500	97–103	98.5–101.5			90–103				95–101	90
10	2,300	4,000	500	97–103	98.5–101.5			90–103				95–101	90

Fire-Service Type, Type I and Type II (ANSI/AWWA C703) (Test at intermediate rate not necessary.)§

	Maximum Rate (All Meters)				Change Over Point (All Meters)				Minimum Rate (New and Rebuilt)			Minimum (Repaired)
Size	Flow Rate†	Test Quantity††		Accuracy Limits	Flow Rate**	Test Quan- tity††		Accuracy Limits	Flow Rate	Test Quantity††		Accuracy Limits
	<i>gpm</i>	<i>gal</i>	<i>ft³</i>	<i>percent</i>	<i>gpm</i>	<i>gal</i>	<i>ft³</i>	<i>percent</i>	<i>gpm</i>	<i>gal</i>	<i>ft³</i>	<i>percent</i>
<i>in.</i>				Type I								<i>percent (min)</i>
				Type II								
3	350	700	100	97–103								90
4	700	1,500	200	97–103								90
6	1,600	3,000	400	97–103								90
8	2,800	5,000	700	97–103								90
10	4,400	9,000	1,200	97–103								90

Continued

Fire Service Type, Type III (ANSI/AWWA C703)

Size	Maximum Rate (All Meters)			Intermediate Rate (All Meters)			Minimum Rate (New and Rebuilt)			Minimum (Repaired)	
	Flow Rate†	Test Quantity††	Accuracy Limits	Flow Rate**	Test Quantity††	Accuracy Limits	Flow Rate	Test Quantity††	Accuracy Limits	Accuracy Limits	Accuracy Limits
<i>in.</i>	<i>gpm</i>	<i>gal</i>	<i>percent</i>	<i>gpm</i>	<i>gal</i>	<i>percent</i>	<i>gpm</i>	<i>gal</i>	<i>percent</i>	<i>percent (min)</i>	
3	350	700	98.5–101.5	10	100	98.5–101.5	4	100	95–101.5	—	—
4	700	1,500	98.5–101.5	30	500	98.5–101.5	10	100	95–101.5	—	—
6	1,600	3,000	98.5–101.5	60	1000	98.5–101.5	20	1000	95–101.5	—	—
8	2,800	5,000	98.5–101.5	70	1000	98.5–101.5	30	1000	95–101.5	—	—
10	4,400	9,000	98.5–101.5	110	1000	98.5–101.5	35	1000	95–101.5	—	—

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**Electromagnetic and Ultrasonic Meters for Revenue Applications,
Type I (ANSI/AWWA C715)**

Size	Maximum Rate (All Meters)			Intermediate Rate (All Meters)			Minimum Rate (New and Rebuilt)			Minimum (Repaired) Accuracy Limits
	Flow Rate† gpm	Test Quantity†† gal	Accuracy Limits percent	Flow Rate** gpm	Test Quantity†† gal	Accuracy Limits percent	Flow Rate§§ gpm	Test Quantity†† gal	Accuracy Limits§§ percent	
in.										
1/2	8	100	98.5–101.5	0.35	10	98.5–101.5	0.11 (0.18)	10	95–105 (98.5–101.5)	—
5/8	15	100	98.5–101.5	0.4	10	98.5–101.5	0.13 (0.20)	10	95–105 (98.5–101.5)	—
3/4	25	100	98.5–101.5	1	10	98.5–101.5	0.15 (0.5)	10	95–105 (98.5–101.5)	—
1	40	100	98.5–101.5	1.5	10	98.5–101.5	0.3 (0.75)	10	95–105 (98.5–101.5)	—
1½	60	100	98.5–101.5	4	100	98.5–101.5	0.6 (2)	100	95–105 (98.5–101.5)	—
2	100	100	98.5–101.5	5	100	98.5–101.5	1 (2.5)	100	95–105 (98.5–101.5)	—
3	200	500	98.5–101.5	15	100	98.5–101.5	2.5 (7.5)	100	95–105 (98.5–101.5)	—
4	400	1,000	98.5–101.5	20	500	98.5–101.5	3.5 (10)	300	95–105 (98.5–101.5)	—
6	800	2,000	98.5–101.5	40	1,000	98.5–101.5	9 (20)	300	95–105 (98.5–101.5)	—
8	1,000	5,000	98.5–101.5	80	3,000	98.5–101.5	18 (40)	2,000	95–105 (98.5–101.5)	—

Continued

**Electromagnetic and Ultrasonic Meters for Revenue Applications,
Type II (ANSI/AWWA C715)**

Size	Maximum Rate (All Meters)			Intermediate Rate (All Meters)			Minimum Rate (New and Rebuilt)			Minimum (Repaired) Accuracy Limits
	Flow Rate† <i>gpm</i>	Test Quantity†† <i>gal</i>	Accuracy Limits <i>percent</i>	Flow Rate** <i>gpm</i>	Test Quantity†† <i>gal</i>	Accuracy Limits <i>percent</i>	Flow Rate <i>gpm</i>	Test Quantity†† <i>gal</i>	Accuracy Limits <i>percent</i>	
<i>in.</i>		<i>ft³</i>			<i>ft³</i>			<i>ft³</i>		<i>percent (min)</i>
1/2	8	100	98.5–101.5	2	10	98.5–101.5	0.25	10	95–105	—
5/8	15	100	98.5–101.5	2	10	98.5–101.5	0.25	10	95–105	—
3/4	25	100	98.5–101.5	4	10	98.5–101.5	0.5	10	95–105	—
1	40	100	98.5–101.5	6	10	98.5–101.5	0.75	10	95–105	—
1½	100	100	98.5–101.5	8	100	98.5–101.5	1.5	100	95–105	—
2	150	100	98.5–101.5	12	100	98.5–101.5	2	100	95–105	—
3	350	500	98.5–101.5	30	100	98.5–101.5	4	100	95–105	—
4	600	1,000	98.5–101.5	50	500	98.5–101.5	7.5	300	95–105	—
6	800	2,000	98.5–101.5	110	1,000	98.5–101.5	15	300	95–105	—
8	2,000	5,000	98.5–101.5	200	3,000	98.5–101.5	30	2,000	95–105	—
10	3,000	7,000	98.5–101.5	300	5,000	98.5–101.5	50	3,000	95–105	—
12	4,000	10,000	98.5–101.5	400	5,000	98.5–101.5	65	3,000	95–105	—
16	5,500	50,000	98.5–101.5	750	30,000	98.5–101.5	110	20,000	95–105	—
20	8,000	50,000	98.5–101.5	1,100	30,000	98.5–101.5	175	20,000	95–105	—

**Meters for Residential Fire Sprinkler Systems in One- and Two-Family
Dwellings and Manufactured Homes (ANSI/AWWA C714)**

Size	Maximum Rate (All Meters)			Intermediate Rate (All Meters)			Minimum Rate (New and Rebuilt)			Minimum (Repaired) Accuracy Limits
	Flow Rate† <i>gpm</i>	Test Quantity†† <i>gal</i>	Accuracy Limits <i>percent</i>	Flow Rate** <i>gpm</i>	Test Quantity†† <i>gal</i>	Accuracy Limits <i>percent</i>	Flow Rate§§ <i>gpm</i>	Test Quantity†† <i>gal</i>	Accuracy Limits <i>percent</i>	
<i>in.</i>		<i>ft³</i>			<i>ft³</i>			<i>ft³</i>		<i>percent (min)</i>
3/4	25	100	98–102	3	10	98–102	1/2	10	95–103	90
1	40	100	98–102	4	10	98–102	3/4	10	95–103	90
1½	50	100	98–102	8	100	98–102	1½	100	95–103	90
2	100	100	98–102	15	100	98–102	2	100	95–103	90

Continued

* A rebuilt meter is one that has had the measuring element replaced with a factory-made new unit. A repaired meter is one that has had the old measuring element cleaned and refurbished in a utility repair shop.

† These are suggested test flows and test quantities. Testing for high rates of flow can be achieved by testing the meter at 25% of the meters rating if the manufacturer's original test certificate indicates a linear curve between 25% and 100% of the rated flow range.

†† Quantity should be one or more full revolutions of the test hand / initial dial (see "Maximum Indication on Initial Dial" values specified in mechanical meter standards such as ANSI/AWWA C700, C701, and so on), or a quantity not less than the "Maximum Allowable Indication on Initial Display" values specified in ANSI/AWWA C715. Quantity should result in not less than 3 minutes running. When limited test capabilities force the use of smaller test quantities, the resultant increase in total test uncertainties and errors need to be recognized when establishing acceptance criteria tolerance.

§ The bypass meter should be tested in accordance with the appropriate test requirements for the type of meter used.

** As this rate varies according to manufacturer, it should be determined for each type of meter tested.

§§ Minimum test flow rates with corresponding accuracy limits in parentheses () are alternative values, to accommodate concerns over test times or concerns over test benches being able to conduct testing at the smaller flow rates (without parentheses) reliably. Note that the flow rate values in parentheses are the lowest rates for the normal test limits from ANSI/AWWA C715, and as such would have accuracy limits of 98.5%–101.5%. If these flow rates in parentheses are used in Minimum Rate testing, then the recommended test flow rates for the Intermediate Rate should be twice those listed in the table. However, see the preceding footnote, detailing the preferred use of an intermediate rate determined for each specific make/model.

Metric Conversions: in. $\times$ 25.4 = mm, gal $\times$ 0.003785 = m³, gpm $\times$ 0.2268 = m³/h, ft³ $\times$ 0.02831 = m³.

Water Meters— Selection, Installation, Testing, and Maintenance

AWWA MANUAL M6

Fifth Edition



**American Water Works
Association**



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Water Meters—Selection, Installation, Testing, and Maintenance

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Contents

List of Figures, v

List of Tables, vii

Foreword, ix

Acknowledgments, xi

Chapter 1 History of Water Measurement and Development of Water Meters.....	1
Introduction, 1	
Water Supply in Ancient Times, 1	
Measuring Devices of More Recent Times, 5	
Acceptance of Meters by Water Utilities, 25	
Standardization, 25	
Remote-Reading Devices, 28	
Plastic Parts and Components, 29	
Chapter 2 Selecting Meter Types.....	31
Introduction, 31	
Small Flows, 32	
Medium Flows, 33	
Large Flows, 33	
Chapter 3 Effects of Water-Flow Friction, Increased Usage, and Pressure Losses on Service Adequacy.....	37
Introduction, 37	
Factors to Consider in Sizing Mains, 37	
Friction-Loss Data, 38	
Sample Service Installation Calculation, 41	
Chapter 4 Meter Installation.....	43
Introduction, 43	
Indoor Versus Outdoor Settings, 43	
Meter Installation, 44	
Chapter 5 Testing of Meters—Test Procedures and Equipment.....	53
Introduction, 53	
Accuracy Limits, 54	
Testing New Meters, 57	
Field Testing, 80	
Chapter 6 Maintenance and Repair of Water Meters.....	87
Introduction, 87	
Meter Replacement, 88	
Meter Maintenance and Repair, 89	
Disassembling, 89	
Mechanical-Drive Meter Reassembly, 91	
Repair of Magnetic-Drive Meters, 91	
Conclusion, 91	

Chapter 7 Maintenance Shop Layout and Equipment.....	93
Introduction, 93	
Meter Shop Equipment, 94	
Shop Layout, 97	
Chapter 8 Meter Records.....	103
Introduction, 103	
Elements of a Good Record System, 103	
Paper Meter Records, 106	
Summary, 106	
Chapter 9 Remote Registration	107
History, 107	
Current Status, 108	
Bibliography, 109	
Index, 111	
List of AWWA Manuals, 113	

Figures

- 1-1 Roman adjutage, 3
- 1-2 Pitot tube, 6
- 1-3 Modified Pitot tube, 6
- 1-4 Improved form of the Woltmann meter, 7
- 1-5 Cutaway of an “open or interchangeable” internal mechanism Woltmann-type turbine meter, 8
- 1-6 Cutaway of a “closed” Woltmann-type turbine meter with magnetic drive, 8
- 1-7 Original form of the Woltmann meter, 9
- 1-8 Class I turbine meter, 10
- 1-9 Class II turbine meter, 11
- 1-10 Venturi tube, 11
- 1-11 Orifice meter and differential pressure sensing mercury manometer instrument, 12
- 1-12 Original duplex-piston meter, 14
- 1-13 Early rotary-piston meter, 14
- 1-14 Displacement-type oscillating-piston meter with magnetic drive, 16
- 1-15 Displacement-type nutating-disc meter with magnetic drive, 17
- 1-16 AWWA standard C710 positive displacement meter, nutating-meter type, 17
- 1-17 Cutaway of a dry-head multijet meter without a “frost protection” device, 18
- 1-18 Cutaway of a dry-head multijet meter with a patented “frost protection” device, 18
- 1-19 A section view of the fluidic oscillator internal mechanism, 19
- 1-20 An isometric view of the fluidic oscillator internal mechanism, 19
- 1-21 Simplified drawing of the singlejet meter, 19
- 1-22 Design details of the singlejet meter, 20
- 1-23 Large meter, singlejet design, 20
- 1-24 Compound meter, double-register type, 22
- 1-25 Compound meter, single-register type, 22
- 1-26 Fire-service meter, 24
- 1-27 Propeller meter, 24
- 1-28 A 4-in. ultrasonic meter, 26
- 1-29 A battery-powered electromagnetic meter, 27
- 1-30 A turbine meter with electronic enhancement, 27
- 1-31 Typical plastic-body small-disc meter, 29
- 4-1 Two types of meter setters for vertical indoor piping, 45

- 4-2 Meter arrangements for fire services, 46
- 4-3 Residential fire service fitting, 46
- 4-4 Outdoor meter settings with integral yoke (left) and meter yoke (right), 48
- 4-5 Manifold of large meters, 49
- 4-6 Optimum turbine meter installation, 51
- 5-1 A typical accuracy curve for a $\frac{5}{8}$ -in. (15-mm) meter, 55
- 5-2 Basic requirements for a volumetric meter-testing assembly, 73
- 5-3 Rotameter rate-of-flow indicator, 74
- 5-4 Test bench for small meters, 75
- 5-5 Testing of large meters, 75
- 5-6 Large meter testing facility, 76
- 5-7 Detail of calibration scale of testing tank and sectional view of tank with outlet valve, 77
- 5-8 Automatic cutoff valve, 79
- 5-9 Large multiple-meter test bench, 80
- 5-10 Field-test apparatus for small meters, 82
- 5-11 Field testing flanged meters, 83
- 5-12 Mobile meter test van, 83
- 5-13 Mobile test unit, 84
- 6-1 A meter technician maintaining modern concept water meters, 88
- 6-2 Opening of disc chamber and gauging of chamber ball socket, 90
- 6-3 Examination and assembly of chamber and disc, 90
- 7-1 Suggested layout for small modern repair shop, 99
- 7-2 Suggested layout for medium modern repair shop, 100
- 7-3 Suggested layout for large modern repair shop, 101
- 8-1 Meter history record, 105
- 8-2 Report of meter test and repairs, 106

Tables

- 2-1 Types of meters for water measurement, 32
- 3-1 Elevation above supply main—elevation head, 39
- 3-2 Comparison of computed water flow friction losses for service line, psi/ft, 39
- 3-3 Computed pressure losses for service components, psi, 40
- 3-4 Discharge from fixtures and faucets at various operating pressures, 42
- 4-1 Large meter installation guides for compound meters and class I and II turbine meters, 49
- 5-1 Accuracy limits for compliance with guidelines, 56
- 5-2 State public service commission regulations for periodic testing of water meters as of Nov. 30, 1994, 60
- 5-3 Test requirements for new, rebuilt, and repaired cold-water meters, 63
- 5-4 Percentage registration tables for test quantities other than 10, 100, or 1,000 gal or ft³, 67
- 5-5 1999 sample test meters test results—set date, 70
- 5-6 1999 sample test meters test results—purchase date, 71
- 5-7 1999 sample test meters test results—consumption, 72

Foreword

This manual is a guide to selecting, installing, testing, and maintaining water meters. The manual discusses recommended practices; it is not an AWWA standard calling for compliance with certain specifications. It is intended for use by new and existing utilities of all sizes, either as a textbook for those not fully familiar with meters or as a reference manual. Water utilities may use this manual as a tool to obtain the best revenue for their investment in meters and maintenance facilities. Design engineers and consultants may use this manual in laying out new meter installations or repair shops.

Most readers will first use this manual for assistance on an individual problem; however, for adequate knowledge of the field of water meter usage, the entire manual should be studied. This manual references applicable AWWA standards for the various types of meters. These standards may be purchased by calling AWWA Customer Service (800.926.7337) or through the Bookstore section of the AWWA website, awwa.org.

The AWWA manual on water meters was first published in a series of articles in the June, July, August, and September 1959 issues of *Journal - American Water Works Association* and was compiled as a separate reprint in 1962. A second edition of the manual was published in 1973, as a complete revision, updating and substantially enlarging the 1962 serial edition. The third and fourth editions, published in 1986 and 1999, respectively, reflected the latest revisions of the AWWA meter standards at the time and included substantial updates to the text and photographs.

This fifth edition contains current information from the latest AWWA meter standards, including new AWWA standards on singlejet meters and fluidic-oscillator meters. Since 1999, much has changed in meter reading technology, and the future holds even greater promise.

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Chapter 1

History of Water Measurement and Development of Water Meters

INTRODUCTION

Accurate water measurement is the means by which water utilities produce revenue to cover expenses, charge each customer equitably, prevent waste of water, and minimize the load on wastewater facilities. This concept is universally accepted today, but it took thousands of years for the science of water supply and distribution to reach its present state.

WATER SUPPLY IN ANCIENT TIMES

Roman Adjutages

For nearly half a century, until 312 B.C.E., the citizens of Rome were content to draw their water supply from the Tiber River, wells, and springs. As in our own times, such sources became entirely inadequate to meet the needs of a rapidly growing city, and the first of the great aqueducts, the Appian, was constructed. This was followed 40 years later by the Anio Vetus and during the next three centuries by seven other aqueducts.

All of these aqueducts are described in meticulous detail by water commissioner Sextus Julius Frontinus (approximately A.D. 35 to 104) in his two books of *De Aquis Urbis Romae* (translated into English by Clemens Herschel under the title *The Water Supply of the City of Rome*).

The contributions made by Frontinus cannot be overstated. The office of water commissioner was held, from ancient times, by the most distinguished citizens. Frontinus set an example for all future water commissioners to follow in his honest devotion to duty, thoroughness of accomplishment, and sterling character. Those who read his voluminous report today can still profit and are astonished over the progress made during those ancient times in the development of metal pipe, pipe fittings, plug cocks, inverted siphons, ornate fountains and baths, and possibly in methods of measurement and filtration. Herschel comments:

It must be remembered that we are speaking of the works of a very practical people. They were engineers by nature, rather than architects or men of science only; they taught the useful from choice, rather than that which was merely beautiful in design or tendency. They felt comparatively little predilection for “pursuing science for science’s sake,” as the phrase goes, while they pursued to the utmost of their abilities, and most ably for their day, the “art of directing the great sources of power in nature for the use and convenience of man,” which constitutes the profession of the civil engineer.

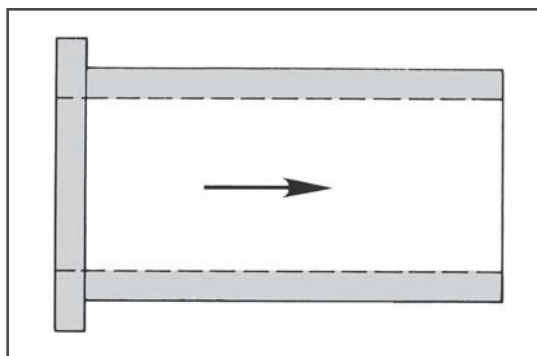
After describing in great detail the construction of the nine huge aqueducts, Frontinus wrote:

Having now given the builders and the age of each aqueduct, also their sources, lengths of channel, and order of heights, it seems to me not out of keeping to go more into detail, and to demonstrate how large is the quantity of water which is allotted to public and to private uses, as well as for luxury; and through how many tanks it is conveyed, and in what wards these are located; *how much water* is distributed within the city walls, how much without, how much is used for water basins, how much for fountains, how much for public structures, how much on account of the state, how much by private consumers. But before I mention the names *quinaria*, *centenaria*, and those of the other adjutages (Figure 1-1) by which water is gaged, I deem it expedient to state what is their origin, what their discharge, capacity, or value, and what each name means; and to show, after presenting the rules according to which their proportions and capacity are computed, how I discovered their discrepancies, and the way I set about to correct them.

The adjutages to measure water are arranged either according to digits or inches. Digits are used down to the present day in Campania, and in very many places in Italy; inches in Apulia and elsewhere. The digit, according to common agreement, is the one sixteenth part of a foot, the inch the twelfth; but even as there is a difference between the inch and digit, so also digits differ among themselves; some are called square, others round. The square digit is greater than the round digit by three fourteenths of itself; the round digit is smaller than the square digit by three elevenths, obviously because the corners are lopped off.

Just a few paragraphs further, we find the amazing statement:

But every adjutage is gaged either by its diameter or circumference, or by its area of clear cross section; from any of which its capacity may be found.



An adjutage was a simple bronze tube of a specific cross section. No precise means for measuring the velocity of water passing through the tube was available.

Figure 1-1 Roman adjutage

It seems natural that we turn to Herschel for pointed comment. He writes:

Let us see what ideas were extant on hydraulics in Frontinus' time: The most troublesome point of ignorance he had to contend with was a total inability to measure the velocity of water, or even to rightly and fully grasp the idea of such velocity, whether as flowing in an open channel or in closed pipes. He accordingly compares streams of water merely by the areas of their cross sections. A square foot of water is all one to him, whether it be one of the 8 sq ft (0.7 m^2) of cross-sectional area of a stream in a conduit, or whether it be composed of the sum of 200 or more cross-sectional areas of lead pipes leading out of delivery tanks to fountains, or to water basins, or to private consumers, and ending and discharging at as many different elevations. To the expert of today, this seems excessively silly; and yet the same thing is constantly being done even now by those who ought to know better. The average man today will talk about "a stream of water that will fill a 6-in. (150-mm) pipe," a perfect parallel to the *quinaria* (0.907 English inch) of Frontinus; and there are hundreds of deeds on record conveying "square feet of water" for power purposes, just as though the law of falling bodies and its application to hydraulics had never been discovered; and unmindful of the fact, as one old Italian writer on water rights has expressed it, that to speak of a stream of water by its area of cross section is like estimating the volume of a cylinder merely from the area of its base.

Yet at least some evidence suggests, as we read Frontinus, that he was frequently troubled over his adoption of pipe area as the sole measure of volume discharge, because at one point in his history he wrote:

Let us not forget in this connection that every stream of water whenever it comes from a higher point and flows into a delivery tank through a short length of pipe, not only comes up to its measure, but yields, moreover, a surplus; but whenever it comes from a low point, that is, under a less(er) head, and is conducted a tolerably long distance it will actually shrink in measure by the resistance of its own conduit so that, on these accounts, either an aid or a check is needed for the discharge.

In other words, a check of some sort was required *to make the pipe discharge the quantity typical for its size*. Frontinus continues:

. . . whence it appears that the amount measured by me is none too large; the explanation of this is that the more impetuous stream of water increases the supply, since it comes from a large and rapidly flowing river.

Herschel comments:

And then he goes on again, worrying himself into all sorts of explanations why his gagings by areas, made irrespective of heads and velocities, do not balance. The frauds of the watermen, of the plumbers, and of others who draw water unlawfully always furnish a handy explanation, however.

We become increasingly perplexed when we realize that Hero of Alexandria, thought by some to be the teacher of Frontinus, had already announced:

Observe always that it does not suffice to determine the section of flow, to know the quantity of water furnished by the spring. This we said was 12 square digits. It is necessary to find the velocity of its current, because the more rapid the flow, the more water the spring will furnish, and the slower it is, the less it will produce. For this reason, after having dug a reservoir under the stream, examine by means of a Sundial how much water flows into it in an hour, and from that deduce the quantity of water furnished in a day. Thus one has no need to measure the section of the stream.

Notwithstanding the false premise of Frontinus, here indeed was the beginning of the art of measuring flowing water, which will be emphasized as we continue on to further developments in Roman practice.

Quoting Herschel:

But some control of the amount drawn had to exist, and we accordingly find that the measure of a grant in the city of Rome, A.D. 97, was the right to insert, at a designated place in the public delivery tanks, or cisterns, which received their supply, either directly or through lead pipes, from the public aqueducts, a circular bronze adjutage, or short piece of pipe, stamped by the public authority, not less than about nine inches long and of a designated diameter, some fifteen such diameters being in ordinary use; and to allow water naturally to flow through this adjutage; it being the law, moreover, to ensure a natural flow through the stamped bronze adjutage, that the lead or other pipe immediately downstream from it should have the same diameter as the adjutage, on a length of not less than 50 ft (15 m), measuring from the downstream end of the adjutage.

Frontinus definitely realized that there were other factors limiting the quantity of water that could be drawn. He wrote:

An adjutage placed at right angles and level, it maintains its proper measure; set against the current of the water and sloping down, it will consume more; set sloping to one side, so that the water flows by, and inclined with the current, that is, placed less favorably for swallowing water, it will receive the water slowly, and in a scant quantity.

It must also be left optional to attach any kind of lead pipe to the adjutages; but there must rather be attached for a length of 50 ft (15 m) one of the same interior area as that which the adjutage has been certified to have, as has been ordained by a vote of the Senate that “no one to whom a right to draw water from the public conduits has been granted shall have the

right to use a larger pipe than a *quinaria* for a space of 50 ft (15 m) from the delivery tank out of which he is to draw the water.”

The water commissioner called attention to fraud that was being practiced by attaching pipes of larger diameter to the adjutages and, as a consequence, the water was not, he said, “held together for the lawful distance.”

The Naples Museum exhibits three small bronze pipes believed to be genuine adjutages 9-in. (230-mm) long and 0.72 in. (18 mm) in diameter. It was required that

- The adjutage be entered at a designated point
- Water rights limited the quantity of water to be drawn and ended with the death of the grantee
- The setting of the orifices be determined by the authorities
- Adjutages be of a prescribed form, dimension, and material (bronze), and bear the official stamp of the authorities

Frontinus reports “cheating practices” discovered, in addition to the larger outlet pipe mentioned, as follows:

To some pipes no adjutages were attached. Such pipes are called uncontrolled, and are expanded or contracted as pleases the watermen.

When a water right is transferred to a new owner they will insert a new adjutage in the delivery tank; the old one they leave in the tank and draw water from it, which they sell.

He adds significantly: “Most especially, therefore, as I believe, should the commissioner have in mind to stop this.”

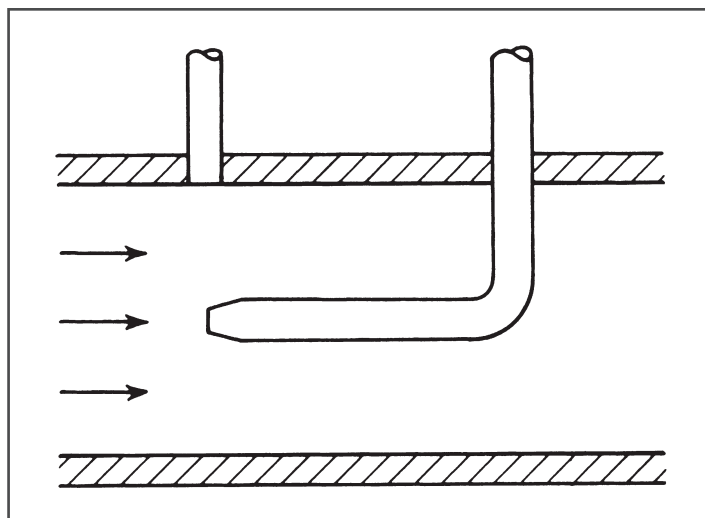
MEASURING DEVICES OF MORE RECENT TIMES

The remainder of this chapter discusses more recent developments in devices for measuring water and their acceptance by water utilities. In addition, standardization issues are discussed.

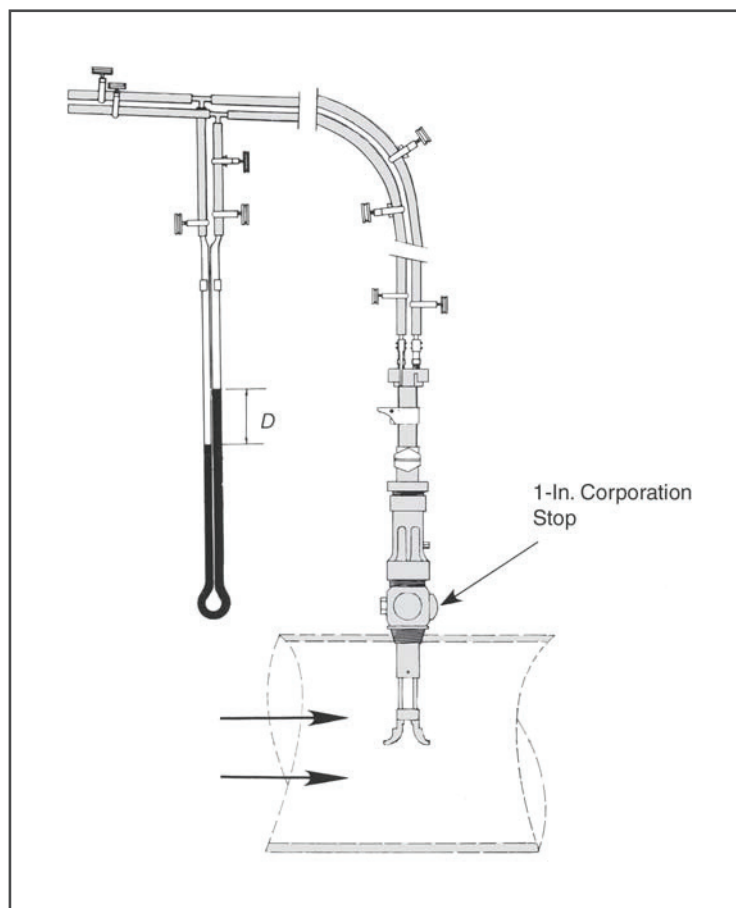
The Pitot Tube

In 1730, Henri Pitot (1695–1771), a distinguished French engineer, performed experiments on the river Seine in which he used a vertical glass tube with the short, 90° tip at the lower end pointing upstream to determine whether there was a relationship between the rise of water in the tube and the velocity of flow (Figure 1-2). Two years later, he contributed a paper to l’Academie Royale des Sciences describing his experiments and his tube, which he had combined with a second, static-head vertical tube. Significantly, his discovery that the height to which the water rose in his tube was proportional to the square of the stream velocity came in the same year that Johann Bernoulli published the fundamental relationship of head to velocity squared of water flowing through pipes.

One hundred and twenty-five years later, Henry Darcy, another French engineer, modified the tube and thus improved the accuracy of the static-head readings and reduced the oscillations of the water columns. Hiram F. Mills of Boston was the first American engineer to use the Pitot tube (1875); John R. Freeman applied the Pitot tube to the measurement of fire-stream jets. The design illustrated in Figure 1-3 is used primarily for this purpose.



The Pitot tube measures the velocity of the flowing fluid by using the velocity head of the stream as an index of velocity.
Figure 1-2 Pitot tube



This form of Pitot tube, designed by Edward S. Cole in 1896, is used in leak surveys and for measuring flow and pipeline capacity.
Figure 1-3 Modified Pitot tube

Today, the temporary measurement of the rate of flow in a large pipe is sometimes necessary, for example, to locate underground leaks or determine variations in flow rates over a 24-hour period. The type of Pitot tube commonly used for these applications (Figure 1-3), developed by Edward S. Cole in 1896, requires a single, very basic connection into the pipeline. This modified Pitot tube depends on the velocity of the flowing water creating flowing pressure greater than the line pressure in the tube pointed upstream and reduction below the line pressure in a similar tube pointed downstream, both located in the center of the pipe. This differential is mathematically converted into a gallons-per-minute flow rate when the internal diameter of the pipe is known.

Current and Turbine Meters

In 1790, Benjamin G. Hoffman, in Hamburg, Germany, published a booklet describing a form of current meter, invented by Reinhard Woltmann (1757–1837), for measuring flowing air and water. This device seems to be the first practical meter for the purpose; it has since changed materially in design and construction.

In general, the meter consisted of a very light waterwheel operated by the current and carrying on its axis a worm for actuating gearing and a totalizer. The rate of flow was computed from the rotations during a given time period. A 1910 American Society of Mechanical Engineers (ASME) paper, entitled “River Discharge,” refers to the earliest type of current meter as being practical only for measuring surface velocity. However, the ASME paper noted, “About 1790, Woltmann modified this wheel so it could be used beneath the surface” (Figures 1-4, 1-5, and 1-6). Each size of meter had to be calibrated individually.

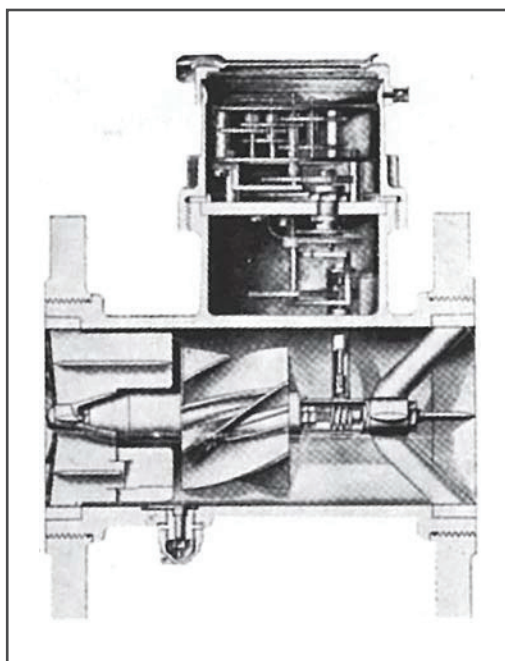


Figure 1-4 Improved form of the Woltmann meter

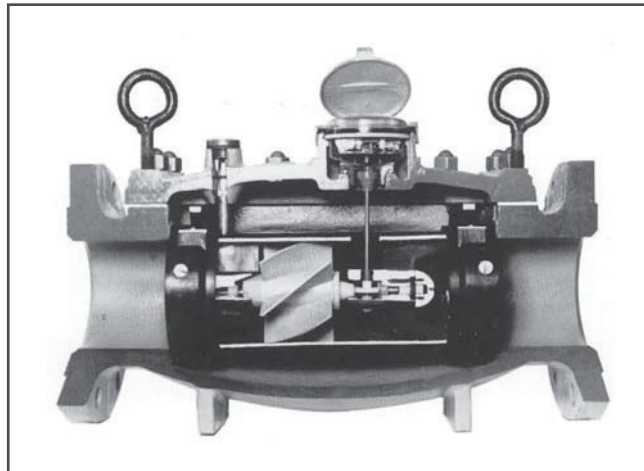


Figure 1-5 Cutaway of an “open or interchangeable” internal mechanism Woltmann-type turbine meter

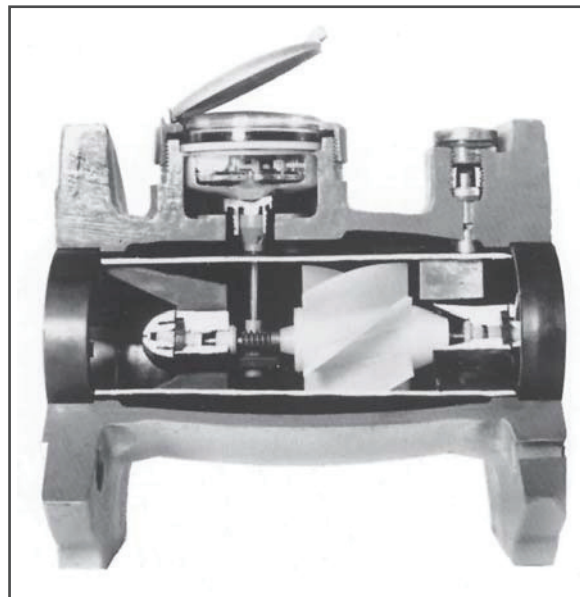
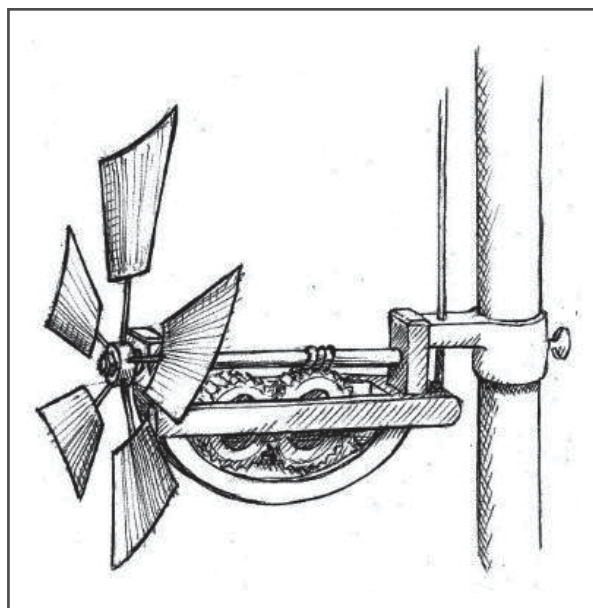


Figure 1-6 Cutaway of a “closed” Woltmann-type turbine meter with magnetic drive

The Woltmann meter (Figure 1-7) was illustrated and described in a German handbook, *Die Hydraulik Und Die Hydraulischen Motoren*, by Georg Meissner, published in Jena, Germany, in 1878. At that time, it was not generally accepted that the meter could be used in a closed pipe. The first English water meter was designed in 1851, by William Siemens (1823–1883). Siemens obtained permission to manufacture this reaction meter in Germany, and the firm of Siemens & Halske began production about 1865. Although such meters appeared to give fairly accurate results, the hydraulic laws governing their action were never fully understood, and the designs were therefore empirical. Corrosion caused considerable trouble because the meter casings were made of cast iron and the internal working parts of bronze.



In this form, the Woltmann meter could measure flows only in an open stream. The revolutions of the waterwheel were transmitted to a register by a gear train. For a stream of known cross section, the register could be calibrated to give accurate measurements of flow.

Figure 1-7 Original form of the Woltmann meter

In 1885, Ross E. Browne, in his book *Water Meters*, described the English Siemens $\frac{1}{2}$ -in. (13-mm) meter, which somewhat resembled a centrifugal pump reversed, using a drum reaction wheel controlled by regulating vanes. The German Siemens was an early form of the rotary-vane meter. Water entered the measuring chamber through angularly positioned inlets, causing the flow to impinge on one side of the vanes of the rotor at a 90° angle. To prevent the rotor from spinning too fast, other, much smaller inlets entered the chamber at an opposite angle, creating a small force in the other direction. This meter was substantially different from the conventional turbine meter in which the water strikes the blades of a rotor at approximately 45° . Today many small rotary-vane meters are manufactured outside the United States.

Whereas the Woltmann meter had a horizontal axis that permitted a straight-through flow, the current or turbine meters developed in the United States since 1890 and until the 1960s usually had a vertical rotor spindle. This design facilitated a vertical drive to the register, but necessitated changes in flow direction within the meter to keep the inlet and outlet in a straight line (Figure 1-8).

With the advent of magnetic drives, some models have returned to the horizontal rotor spindle, which gives lower pressure loss. The first of the modern turbine meters, now referred to as class II turbine meters, was introduced to the market in 1965. Horizontal shaft class I turbines were manufactured for a short time before and during the introduction of horizontal shaft class II turbines. One leading US manufacturer shipped its first unit, called a Torrent meter, in 1896. Its design was later refined to be similar to present construction in Patent 817,887, issued to J.A. Tilden in 1906.

The new class II turbine meter was capable of operating over a much wider flow range than earlier turbine meters, which have been offered by manufacturers since the 1920s. The new horizontal in-line, high-velocity turbine meters are constructed of more modern materials. The new materials for bearings, coupled with low-mass, self-lubricating, low-friction gearing in the registers and gear trains, permit the back loading on the metering elements to be reduced, thus providing improved metering accuracy, range sensitivity, and longevity for this meter.

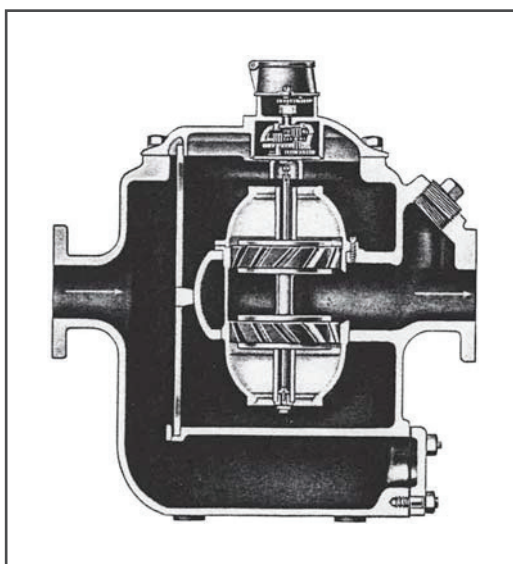


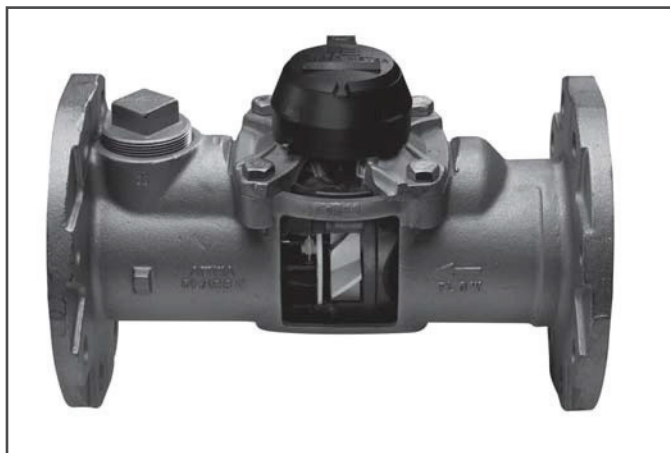
Figure 1-8 Class I turbine meter

The introduction of this newer turbine meter resulted in changes to ANSI/AWWA C701, Standard for Cold Water Meters—Turbine Type, for Customer Service, in 1978. The changes include a newly added distinction between class I and class II turbine meters. Standards for original class I turbines (Figure 1-8) were issued prior to 1978. Class II turbine meters are the newer, in-line, high-velocity type characterized by lower head loss, greater low-flow sensitivity, and tighter accuracy tolerances over a wider flow range (Figure 1-9). The class II turbine meters are considerably smaller and lighter than the class I turbines and afford easier installation as well as smaller accommodations for meter settings. Manufacturers of the class II turbine meters recommend that plate-type strainers be used in the installation upstream from the meter to protect the high-velocity rotors in operation and to decrease the effects of upstream flow disturbances, which affect life and accuracy. Standards for cold-water turbine meters are covered in ANSI/AWWA C701.

In the 1980s, a new version of class I turbine meters was introduced that was similar in size and weight to class II turbine meters. This new class I turbine meter had an internal strainer and a vertical rotor, and thus could be installed in smaller accommodations than many class II turbine meters, which generally require a strainer before the meter.

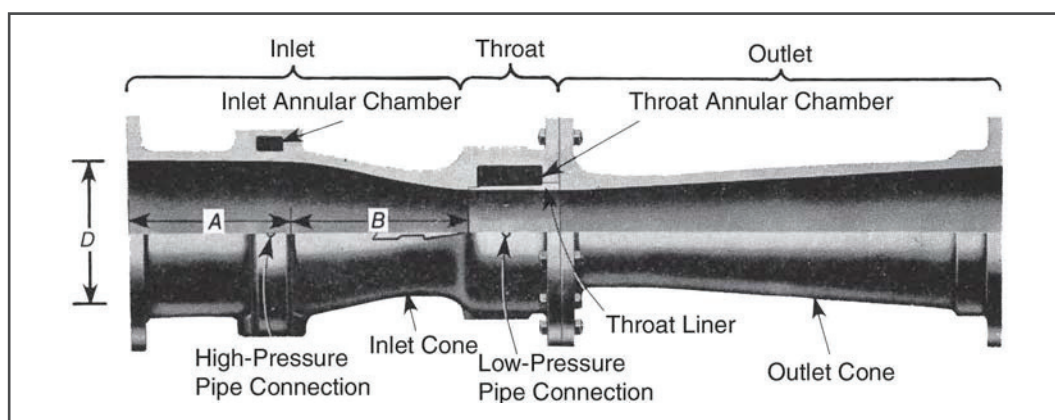
The Venturi Meter

A major contribution to the measurement of flowing water under pressure was Clemens Herschel's invention of the Venturi tube in 1886. A hydraulic engineer with the Holyoke (Mass.) Water Power Company, he was disturbed by the fact that huge quantities of water used by industrial companies, including 25 paper mills, went unmeasured. The tube was based on the principle, discovered a century earlier by the Italian scientist Giovanni Venturi (1746–1822), that the flow of liquid through a converging pipe results in a gain of velocity and a lowering of pressure, whereas the reverse is true in a diverging pipe. The reduction in pressure that occurs at the constriction is actually the result of conversion of pressure head to velocity head. Downstream from the constriction, the velocity head is reconverted to pressure head, so the ultimate result is very little reduction in effective line pressure at some distance downstream.



Courtesy: Badger Meter Inc.

Figure 1-9 Class II turbine meter. Note the test port on top used for pressure testing, air bleeding, and qualitative low-flow tests.



The flow of liquid through a constriction in a pressure conduit results in a lowering of pressure at the constriction. The difference in pressure at the constriction and in the unconstricted portion of the conduit is a function of the flow rate and may be used to calculate the flow rate. The meter has no moving parts in the liquid because it measures pressure differential by means of exterior pressure instruments.

Figure 1-10 Venturi tube

The difference between the full-pressure upstream taps (shown at the left of the constriction in Figure 1-10) and the reduced-pressure taps at the constriction or throat or nozzle (shown in the center of Figure 1-10) is a function of the flow rate and may be used to calculate the flow rate.

The Venturi meter has no moving parts in the stream and is suitable for nearly any size pipeline. One disadvantage of this meter is its length, which makes it bulky and heavy. Recently, however, shorter forms of the Venturi meter, known as flow tubes and flow nozzles, have been developed. These designs have a more abrupt constriction and enlargement. Also, the pressure taps are located differently, which greatly reduces overall length and weight.

One form of mechanical readout is a pressure-actuated pen arm moving across a graduated scale to indicate flow rate or across a moving chart to record the flow rate. More modern versions of the chart recorder are electronic. An integrating attachment

may be added that multiplies the pressure differential times time, and then multiplies that result times a constant or coefficient for the particular size of Venturi to register total flow within commercial tolerances.

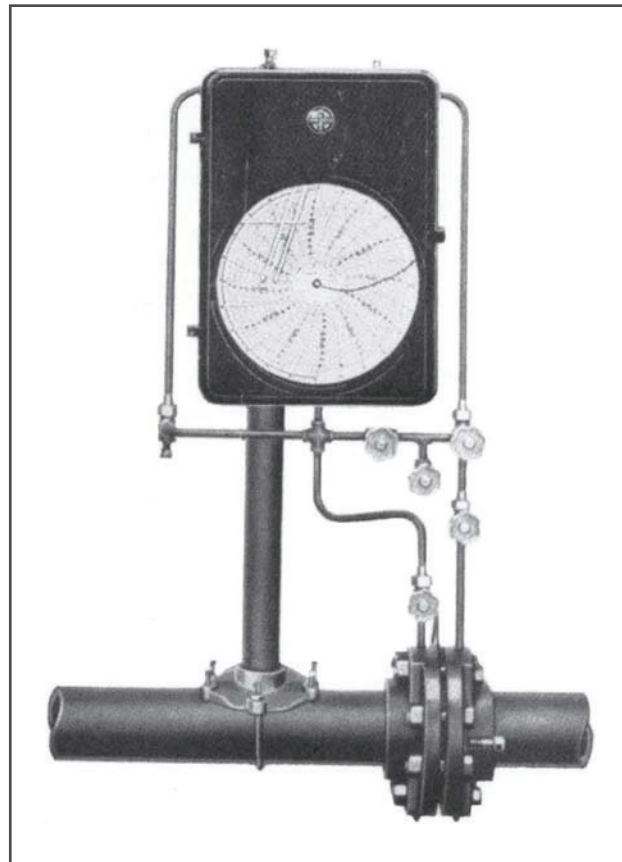
The Orifice Meter

The orifice meter is considered to be one of the oldest devices for measuring or regulating the flow of fluids, dating back to Caesar's Rome. However, development of the thin-plate orifice, the current standard type, did not begin until the early part of the 20th century.

The determination of the relationship between flow rates and differential pressures has been reduced to formulas by which an orifice coefficient can be computed quickly for any size of orifice in any size of pipe.

Modern differential pressure measurement instruments have an electronic output for recording instruments and incorporate electronic microprocessors for calibrated integration of the differential input signal from the meter. The electrical output signal is linear versus flow rate for flow indicators and data loggers.

The orifice sensing unit consists of a round plate with a hole of predetermined size bored in it, usually concentrically; the plate is inserted across a straight run of pipe. Pressure taps are provided either at specified distances upstream and downstream from the orifice plate or within orifice flanges by which the orifice plate is inserted in the line (Figure 1-11).



This meter is mounted directly above a pipeline. The manometer is not shown because it is located behind the two-pen recorder. If a mercury manometer is used in measuring water or steam, seal pots must be placed in the pressure lines to the manometer.

Figure 1-11 Orifice meter and differential pressure sensing mercury manometer instrument

The ASME publication *Fluid Meters* (4th ed.) explained the characteristics of thin-plate orifices:

The pressure of the fluid drops abruptly as it flows through the orifice and, on the outlet side, the pressure continues to decrease slightly. The minimum value is reached a short distance from the outlet side of the orifice. Beyond this minimum point, the pressure increases again, slowly at first, then rapidly for a short distance, then again more slowly until its second maximum is reached several pipe diameters beyond the orifice plate. Since no guiding of the stream occurs on either the inlet or the outlet side of an orifice, the acceleration and deceleration of the fluid stream, which the pressure gradient manifests, is accompanied by considerable turbulence and consequent dissipation of energy (pressure), especially on the outlet side. Consequently, for the same diameter ratio, the downstream maximum pressure is much lower for an orifice than it is for a flow nozzle. In other words, the percentage of differential pressure recovered with an orifice is slightly less than with a nozzle and much less than with a Venturi.

The pressure differential created by the orifice is converted into linear motion of a pen arm, or integrator cam, by a manometer, which may be either a mercury or a sealed-bellows type. By calculating the orifice coefficient and drilling the orifice bore to the diameter required, the chart indicator, scale indicator, or integrator can be read in gallons or other units. This procedure is essentially the same whether a Venturi, an orifice, or some other pressure differential meter is used.

Orifice meters are used where space for the sensing unit is too limited for a Venturi meter and where slightly greater pressure loss can be permitted. The range of flow for maximum accuracy is about $3\frac{1}{2}$ to 1. The sensing unit is relatively inexpensive. Orifice meters are widely used in industrial plants for water, steam, and gas, and by gas utilities.

One water-utility application is to measure the flow of water from pumped wells being tested for flow rates. This operation is feasible provided that (1) the pressure differential between the upstream and downstream taps is not more than the limit of the bellows manometer (maximum limit approximately 14 psi [100 kPa]); (2) the orifice plate and flanges fit the pipe correctly; and (3) the discharge leading to the atmosphere can be kept under slight back pressure.

Displacement Meters

The most popular types of displacement meters originated as modifications of pumps that were run backward. Instead of using the mechanism as a prime mover, the water under pressure moved the piston or disc. The number of strokes or the measured volume per cycle was converted into gallons, cubic feet, or other unit of measurement by appropriate gearing.

Although patents for liquid meters were issued earlier, it is believed that the first American water meter was proposed in 1850 by William Sewell of Williamsburg, N.Y. The first meter actually produced is claimed to have been made by Henry R. Worthington of New York (Figure 1-12). At about the same time (1850s), the George Kent Scientific & Mechanical Group of Luton, England, manufactured a duplex-piston meter of nearly identical design. Samples of this meter exist in several European museums and in displays in Chicago and Baltimore meter shops.

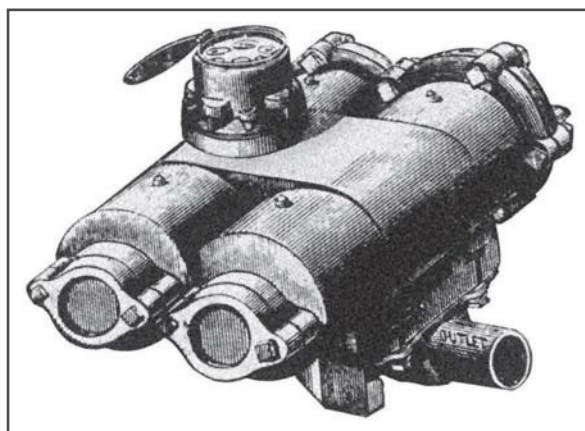
These early meters were of reciprocating piston design, patterned after the familiar D-slide valve used in steam engines. Worthington's original meter consisted of two cylinders and plungers with inlet and outlet ports arranged in such a way that

as water in one cylinder was discharged by the piston, the other cylinder was filling. Water flow through these meters was subject to pulsations caused by the action of the pistons, and high friction losses were encountered. An analysis of the $\frac{5}{8}$ -in. (15-mm) Worthington meter, made in 1885 by Ross E. Browne, describes it as having a capacity of $7\frac{1}{2}$ gpm ($1.7 \text{ m}^3/\text{h}$), weighing 59 lb (27 kg), and costing \$17.00.

Close accuracy was impossible because the meter counted the number of piston strokes, whose length varied with the flow rate. Variations in velocity of the strokes caused variable compression of the rubber cushions at each end of the cylinders.

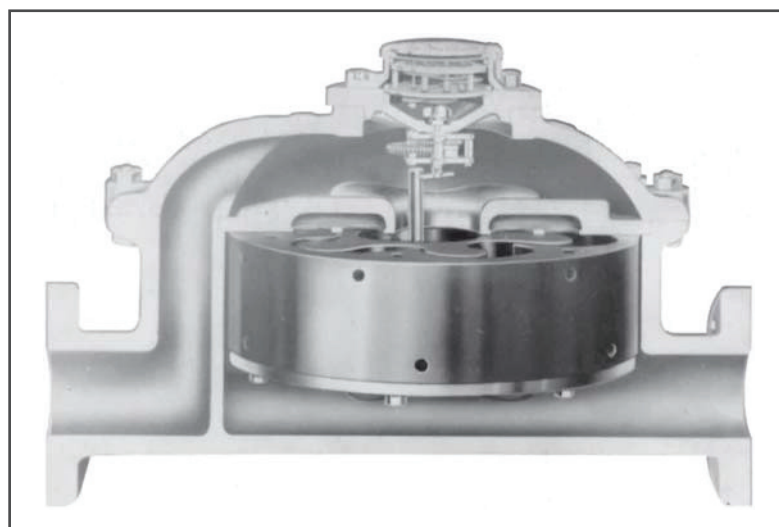
In 1876, a patent was issued for a meter with two rotary pistons. A design for only one piston followed around 1880 (Figure 1-13). The piston rotated within a toothed, fixed cylinder called a crown. In 1885, this design was manufactured in France as the Nasch Crown meter and was also sold in the United States.

Browne also described a single-piston, double-acting meter, the Kennedy. In 1885, it weighed 162 lb (73 kg) in the $\frac{1}{2}$ -in. (13-mm) size and sold for \$27.83. It measured the travel distance of the piston.



Invented in the 1850s, this was the first practical meter produced in the United States.

Figure 1-12 Original duplex-piston meter



Although an improvement over the two-piston design, this type of meter was subject to high friction losses.

Figure 1-13 Early rotary-piston meter

Between 1870 and 1910, more than 400 patents were issued on liquid meters. Many of these patents described constructions that were hopelessly impractical and complicated; others protected any possible variation of valuable features. One of these patents (114,694), issued to J.P. Lindsay in 1871, described an oscillating disc meter, which today would be called a reciprocating meter with a single piston. This meter was round and flat in shape and controlled by a reversing valve. Most of these early designs had impractical features, such as the use of moving valves; the need for some parts to start and stop during each cycle of measurement; the use of floats, of back-and-forth oscillating motion of the piston, and of the inner face of the housing as the measuring chamber; the inlet and outlet not on a common axis centered in the meter; inadequate capacity resulting in excessive pressure loss; and apparently no consideration for manufacturing costs.

Also, these meters, although purporting to be displacement meters, were only semipositive. The high friction load and complex moving parts must have permitted much slippage, thus impairing low-flow accuracy. Present displacement meters have capillary seals rather than packing seals to prevent slippage, but, in any event, the excellence of manufacture reduces slippage to a negligible factor.

In 1884, the first practical oscillating-piston meter patent was issued to Lewis H. Nash. He stated in his patent that this meter was an adaptation of an existing steam engine, but the piston shape and movement are similar to the oscillating-piston meters of today. It was a simple, workable measuring unit.

The nutating-piston principle of motion (now the disc meter) is reported to have been invented in the 1830s by an English clergyman and used in a steam engine. During the 1840s, it was an accepted type of engine, and the presses of the London *Times* were run by this type of engine. However, it was not an efficient prime mover because of the lack of sufficiently tight packing around the edge of the disc portion of the piston; thus it fell into disuse.

A nutating-piston liquid pump, using what today would be called a conical disc, was patented in the United States in 1854 by D.S. Carpenter (Patent 11,776). A modification, also for use as a pump, was patented by Charles H. Hersey in 1868.

The date of the first nutating-piston or disc meter is not clear. Limited patents on this type were issued in 1887 and 1888, and Patent 486,992, issued in 1892 to J.A. Tilden, covered features of a flat-disc meter. In that same year, two companies that are still in the meter business today were organized, one to manufacture conical-disc meters and the other flat-disc meters. A third company was already making conical-disc meters.

All these manufacturers had problems with hard rubber discs breaking at fast flows. One solution, developed by John Thomson in his Patents 476,102; 485,437 (1892); and 535,641 (1895); was for a thrust roller to control the circumferential thrust of the disc in its movement and thus prevent jamming of the disc against the diaphragm at the slot. This method continues to be widely used.

Another approach was to mold a metal reinforcement into the hard rubber disc section of the nutating piston. The diaphragm was then used as a thrust plate to prevent rotation. In all these designs, the disc section (whether flat or conical) was made as thin as possible to reduce weight; however, this necessitated a very close fit between the edge of the disc and the chamber wall to minimize slippage. In 1892, G.B. Bassett designed and began manufacturing $\frac{5}{8}$ -in. (15-mm) conical-disc meters with the disc section $\frac{1}{4}$ -in. (6-mm) thick, instead of $\frac{3}{32}$ in. (2 mm) or less. He found the added weight to be no apparent disadvantage, but the greater thickness gave a more perfect capillary seal against slippage for a given clearance. A reinforcing plate was later added.

The early use of meters was largely in the north, where freezing troubles were frequent. In cold weather, many homeowners drained water pipes at night. The conical-disc meter was favored at this time, because it could be drained more readily than

the flat-disc type. To prevent frost damage when pipes were not drained, two features were developed. John Thomson's Patent 520,197 of 1894 covered a breakable frost bottom to be "blown out by the expansive action of freezing." His Patent 771,337 of 1904 covered the use of bolts that would "break, strip or yield resiliently" under pressure greater than normal but yet within the strength of the casings.

Protection of the reducing gear train against wear by enclosing the gears in a grease-filled chamber came into widespread use following World War I. The grease-filled chamber was actually a very old device. The French Nasch meter of 1885 had this feature, as did the English Siemens. Other early patents implied it, without claiming the chamber as invention. The oil-enclosed gear train remained standard until the advent of magnetic-drive meters between 1958 and 1960.

New magnetic materials that retained a high magnetic power indefinitely and were inexpensive were developed, which led to a major change in small-meter design. In the late 1950s, the magnetic drive was developed by several companies, most of which used small four-pole, and later two-pole, usually round, ceramic magnets. (Details are described in chapter 6.) The use of these magnets eliminated the stuffing box and gear train, transmitting the motion through the top of the bronze casing by magnetic flux. By 1970, almost all small meters built in the United States and many large ones were of this design (Figures 1-14, 1-15, and 1-16.) Present standards for displacement meters are ANSI/AWWA C700, Standard for Cold-Water Meters—Displacement Type, Bronze Main Case; and ANSI/AWWA C710, Standard for Cold-Water Meters—Displacement Type, Plastic Main Case.

Multijet Meters

Multijet meters were first designed and produced in Germany beginning with Siemens & Halske in 1867. At least one US meter manufacturer marketed a multijet meter in the late 1920s and into the 1930s for export, primarily to Latin American countries. They have been available to the US water industry since the early 1960s.

Multijet meters are manufactured in two basic designs, classified as wet- and dry-register models (see Figures 1-17 and 1-18.) The introduction of magnetic drives for meters has made the dry-register meter more prevalent. The multijet meter uses the inferential measuring element principle.

Tangential openings in the chamber direct the water flow across a multivaned rotor. The output speed of the rotor is proportional to the quantity of water passing through the measuring chamber.



This meter has a permanently sealed register unit with no changeable calibrating gears.

Figure 1-14 Displacement-type oscillating-piston meter with magnetic drive