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NASA TECHNICAL MEMORANDUM

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AN AUTOMATED SECONDARY STANDARD FOR CALIBRATING LIQUID FLOWMETERS

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AN AUTOMATED SECONDARY STANDARD FOR CALIBRATING LIQUID FLOWMETERS

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ABSTRACT

A secondary working standard of flow calibration has been developed to be used in place of a primary weight-time standard, and which can thereby effect a 75 percent reduction in calibration time while maintaining acceptable accuracies. The secondary standard uses six previously calibrated turbine-type flowmeters built into two manifold systems containing automatically switched flow valves. The pair of systems is capable of covering the flow range of 0.0004 to 19 l/s (0.007 to 300 gpm) with the uncertainty in volume flow rate not exceeding ±0.25 percent over the range 0.06 to 19 l/s and not exceeding ±0.5 percent over the range 0.0004 to 0.06 l/s. Data reduction and plotting of results are by computer.

INTRODUCTION

Large numbers of flowmeters are in use at various facilities throughout the Lewis Research Center. For the measurement of liquid flow rates, the turbine-type flowmeter is the most widely used instrument; it is followed in frequency of use by head-type and variable-area-type flowmeters.

Aside from their obvious function of measuring fuel flow rate, these flowmeters are used in such diverse applications as monitoring oil flow rate to bearings, measuring coolant flow rate in heat transfer systems, measurement of cryogenics, etc. Because of the large number of meters in use at Lewis, there has been a need for a secondary standard calibration system capable of performing rapid, accurate calibrations.

For many years the primary reference standard has been the weight-time dynamic calibrator. The high accuracy attainable with this device is obtained at the cost of a relatively long time required to perform a calibration. Some alternatives to the weight-time calibration method have appeared in the literature in recent years. Reference 1 mentions the use of a reference flowmeter for comparison calibrations and reference 2 describes various calibration techniques including the calibration of a turbine flowmeter with a second calibrated turbine flowmeter. This report describes a secondary flow standard based on "master" turbine-type flowmeters built into a manifold system with automatically switched valves. The system covers the flow range 0.0004 to 19 l/s (0.007 to 300 gpm) with acceptable limits of accuracy and vastly reduced calibration times. The primary weight-time system is used to calibrate the secondary standard system occasionally, but infrequently.

This report also describes the automatic data reduction and plotting of calibration results by computer.

APPARATUS AND PROCEDURE

Manifold System

There are two similar manifold systems differing only in physical size. Each system consists of three flowmeters and two electrically operated valves connected in a series-parallel arrangement. Connections to either manifold are made with flexible hoses having quick disconnect end fittings. Figure 1 is a schematic drawing of one of the manifold systems.

At very low flow rates both valves are closed and meters are connected in series with the output of the smallest meter displayed on the readout. As the flow increases to the point of maximum flow for the smallest size meter, the smaller valve opens to shunt the smallest meter and the output of the next larger size meter is displayed, and so on. Because the impedance of a meter is greater than that of the ball-type valves, overranging of any meter is avoided. Figure 2 is a photograph of both manifolds showing all six master flowmeters mounted on a portable cart.

Designed for use with water as the measured fluid, all wetted materials are either brass or stainless steel to prevent corrosion. Each meter is located downstream of ten diameters of straight tubing, or a straightening vane, or both, to minimize swirl. Furthermore, the meters are calibrated *in situ* to eliminate effects of changes in piping configuration. Table 1 lists characteristics of the six meters used in the two manifolds. There is a backup meter for each size in case of failure.

It is apparent that the success of the manifold system depends on not having any valve leakage. The type of ball valve used has a brass body with a chrome-plated ball and teflon seals. The valves are not subjected to temperatures other than ambient, and pressure differentials are low. One year's experience shows no evidence that the valves leak.

Flow Controller and Readout

The flow controller shown schematically in figure 1 is the brain of the system. This instrument can accommodate the output of three flowmeters. Depending on the flow rate, internal logic circuitry adjusts the air-operated electrically controlled ball valves to select the proper size of meter and also to display the output of the selected meter. There are provisions to adjust the up and down switchover frequencies at limits to provide an overlap between meters, to prevent hunting. Additional features include the choice of automatic or manual control and the availability of thumbswitches on each channel to adjust the time base for displaying the output in engineering units, if desired.

The counters used to measure outputs of both the test and master meters are designed to measure low frequency by utilizing precise period-measuring techniques and then to calculate and display the frequency in hertz.

Primary Standard

Turbine flowmeter manifold systems are commercially available; however, one of the unique features of the system described herein is its use in conjunction with a primary-standard dynamic weight-time calibrator. This primary standard has a dual flow range which corresponds to the ranges of the high- and low-flow manifolds. There is sufficient overlap in ranges between the two manifold systems so that only one of them is needed to cover the entire flow range of any size of test meter. Figure 3 shows the connections between the primary and secondary standards and the meter being tested. For the sake of simplicity, only one range of both the primary and secondary systems is shown in figure 3.

The primary standard has four functions: (1) to produce the flow; (2) to provide clean, filtered water at constant temperature; (3) to control the flow; and (4) to permit calibration of the master flowmeters, in situ, at any time. The probable error (p.e.) of the primary standard is 0.10 percent. The primary standard has the ability to produce flow rates up to 19 l/s (300 gpm) and to maintain a preset temperature to within ±0.5° C. The flow rate is infinitely adjustable over the range, and once set at a particular rate, will remain constant to within 0.1% with minimum pulsations.

CALIBRATION PROCEDURE

Master Flowmeter Preparation

All six master meters were first calibrated over the flow range of each meter using the primary standard. Calibration results are plotted as meter sensitivity, K, in cycles per unit volume against meter output, F, in hertz. The calibration fluid was water at 24° C. The meters were calibrated two additional times to check repeatability, which was approximately ±0.15 percent with the exception of the smallest meter, whose repeatability was ±0.4 percent. An average curve was drawn through the three sets of data points and from this curve a table of F vs. K for each meter was formed and stored in a computer. The interval between successive F-values in the table varied with the slope of the curve so that a straight line interpolation between any two adjacent points in the table did not deviate from any average curve by more than ±0.25 percent and in most cases by less than ±0.1 percent. The number of points varied from 5 to 15.

Figure 4 shows the difference in calibration curve shape between the largest and smallest size meters. ordinates have been normalized to provide a clearer comparison between the meters. Measuring flow rates below about 0.006 l/s (0.1 gpm) with turbine-type flowmeters becomes increasingly difficult, for the ratio of driving torque on the flowmeter rotor to retarding forces (magnetic, viscous, or frictional drag) is reduced, and as a result, linearity and repeatability are degraded.

Two important precautions involving the handling of the master meters are carefully observed. First, at the completion of any daily operation where the meters are wetted, they are removed from the manifold, flushed and immersed in alcohol, and then dried with a hot air gun at a temperature of about 70° C. Second, because the meter end connections are stainless steel AN-flare-type tube fittings, soft copper conical seals are used to provide leak-free joints and also to avoid having to exert excessive wrench torque, which might cause thread galling or meter body deformation and consequent calibration shifts.

Test Meter

The meter to be calibrated is installed between the primary standard and the manifold system as shown in figure 3. The usual precautions of having adequate lengths of straight pipe upstream and downstream and/or the use of straightening vanes are observed. These precautions are particularly important where the test meter range is at the low end of the manifold-system range, because a reducer and an expander must be used to connect the test meter to the calibration system.

Experience has shown that new or rebuilt turbine-type flowmeters require a run-in period of at least 15 minutes at full flow prior to taking data, in order to stabilize their calibrations. The majority of test meters are turbine-type. However the secondary standard is also very convenient for testing or setting flow switches, determining the C_v of valves, and calibrating head-type and variable-area flowmeters.

Data Collection

During the run-in period of a turbine-type meter, the temperature of the fluid is brought to 24° C (the same temperature at which the master meters were calibrated) and the output of the test meter is examined on an oscilloscope to verify proper functioning. The flow rate is adjusted to the full scale of the test meter and held long enough to record the frequency F_t of the test meter, the frequency F_m of the master meter and also to identify which master is in use, N_m. Between 12 and 15 flow settings, equally spaced on a logarithmic scale, cover the range of the test meter. Since the final calibration curve is presented on a rectilinear plot, this results in a closer spacing of data at the low end of the range, that helps to define the knee or drop-off of the curve.

The flow rate generated by the primary standard is very constant. Flowmeters in good working condition will produce outputs that vary less than 1 percent during the duration of a given setting.

At the conclusion of a calibration test, the piping of the manifold is blown dry with clean, dry compressed instrument air. If the meter tested was a turbine-type flowmeter, the same cleaning and drying procedure is used for this meter as described for the master flowmeters.

DATA REDUCTION

Figure 5 is a block diagram of the flow of data from the flowmeters to the end product, which is a printed table of results and a plot of K against output frequency.

The program developed for use with the secondary standard flow system has three modes. The first, "UPDATE," is for the purpose of storing the previously determined table of K vs. F for each of the master meters. Each table is identified by the number of the master, N_m, and is used to determine the volume flow rate through the system. If a master meter is recalibrated and a shift in calibration necessitates a new table, the old data are automatically erased as the new data are inserted.

The "DISPLAY" mode produces a hard copy of any stored table requested. The most common use of this mode is checking for typing errors after inserting a new table of values.

The "DATA" mode is used to calculate the value of the test-meter factor K_t, at each frequency F_t. The terminal prompts the operator for the values of N_m, F_m, and F_t. With the flowmeters connected in series, volume flowrate is the same through each meter, and since the master meter was calibrated at the same temperature as the test meter, the volume flow rate is computed from the stored tables as $V = F_m/K_m$ and K_t is simply: $K_t = K_m \times (F_t/F_m)$. Heading information such as meter manufacturer, size, model number, serial number, etc. are included with each set of data for identification and these headings are reproduced on the final results.

Figure 6 is a typical table produced by the computer and figure 7 is a typical graph plotted from values in the table. The plotting subroutine examines the ranges of both K and F, and determines the grid spacing such that a ratio of about 1 percent per inch is used for the ordinate, and increments of 100 or 200 hertz per division are used for the abscissa.

An alternative method of plotting which might have merit would be to normalize the K factor by dividing each value of K by K_{fs}, the full scale value of K. The value of K_{fs} would have to be printed on the graph. This method of presentation makes it easy to determine at a glance over what frequency range the factor K remains constant to any predetermined limit. In either case, only the coordinates of the calibration points are plotted, the reasons being that some of the curves have complex shapes and some engineering judgment is needed in drawing the best curve. Also, it is easier to eliminate a bad data point, if necessary.

CONCLUDING REMARKS

In order to reduce manpower spent on routine flowmeter calibrations, an automated secondary standard has been developed. Approximately one hour is required to perform a calibration on the primary standard. This time is reduced to about fifteen minutes when using the secondary standard. At the present time the major portion of liquid flow calibrations are performed on the secondary standard, the exception being special cases that require either calibration at some temperature other than ambient, or calibration inaccuracies not exceeding ±0.15 percent.

Accuracies of meter calibrations performed with the secondary standard approach 99.75 percent. This accuracy statement is based upon knowing the magnitude of errors associated with each of the measurements being made. The master meters have a p.e. of ±0.2 percent, F_t and F_m have a p.e. of ±0.10 percent, and errors due to density changes are eliminated by maintaining a constant temperature for all calibrations of both master and test meters.

Initially the master meters were checked against the primary standard every few weeks to assure reproducibility. This time interval has been extended to over a month because of the good repeatability indicated by these checks. During the past 12 months, experience with the six master meters has shown that only one of the meters suffered a calibration shift of over 1/4 percent. The bearings were replaced on this meter and this problem was resolved. This good record of reliability can probably be attributed to the careful handling given the masters. Although an extra set of meters was purchased initially as spares, none of the masters has needed replacement after about one year of service.

REFERENCES

(1) 1972. "Installation, and Calibration of Turbine Flowmeters," Instrument Society of America Spec. ISA-RP31.1.

(2) Olsen, L. O. 1974. "Introduction to Liquid Flowmeters," National Bureau of Standards Rept. NBS-TN-831.

TABLE 1. - MASTER FLOWMETER CHARACTERISTICS

Manifold	Meter no.	Flow range		Frequency, Hz (full scale)	Linearity,[a] at ±0.5 percent	Repeatability,[b] average deviation, percent
		liters/sec	gpm			
High range	1	1.6 to 20	25 to 300	1800	18:1	0.11
	2	0.2 to 1.6	2.5 to 25	1500	7:1	.17
	3	0.02 to 0.20	0.25 to 2.5	1300	2:1	.13
Low range	4	0.05 to 0.6	0.75 to 9	1600	16:1	0.11
	5	0.005 to 0.05	0.075 to 0.75	1500	1.2:1	.16
	6	0.0004 to 0.005	0.007 to 0.075	1260	2:1	.39

[a]The ratio of full scale frequency (F_{fs}) to the frequency at the point where K deviates from K_{fs} by ±0.5 percent.

[b]The average deviation of data points from the mean curve drawn through three separate calibrations.

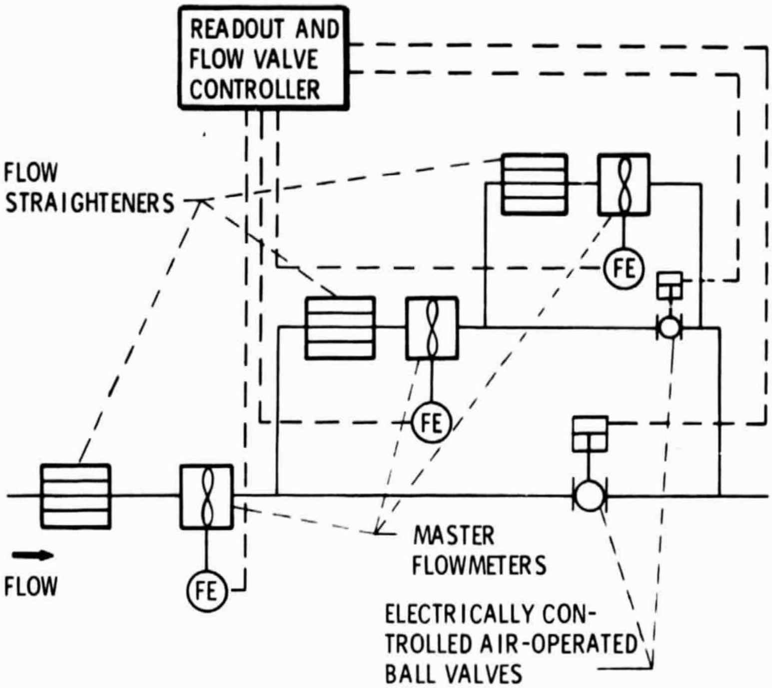

Figure 1. - Schematic of one of the two manifold systems.

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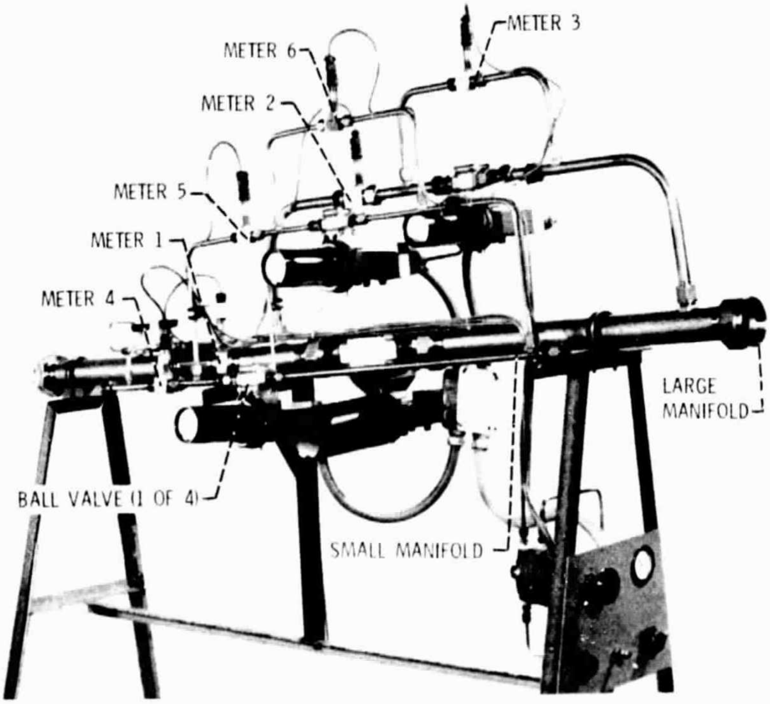

Figure 2. - Complete manifold system.

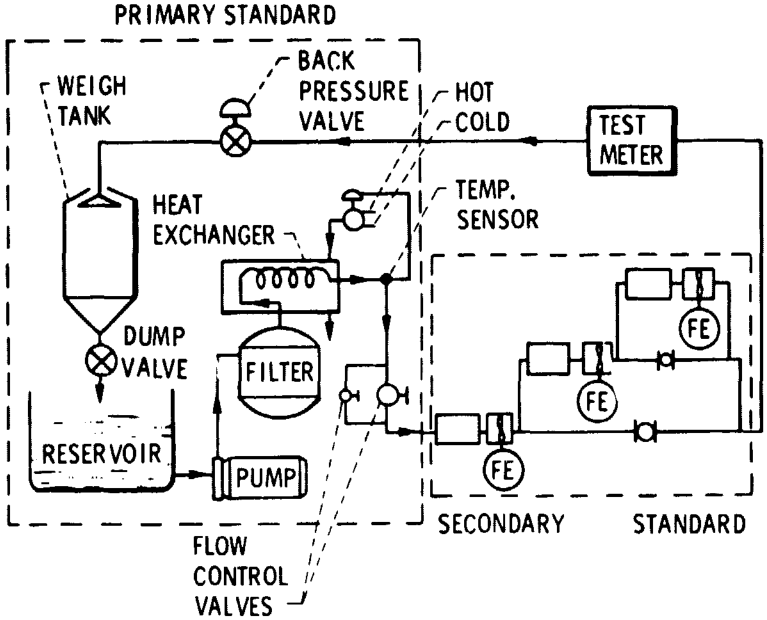

Figure 3. - Schematic of one ra:.ge of complete flow loop.

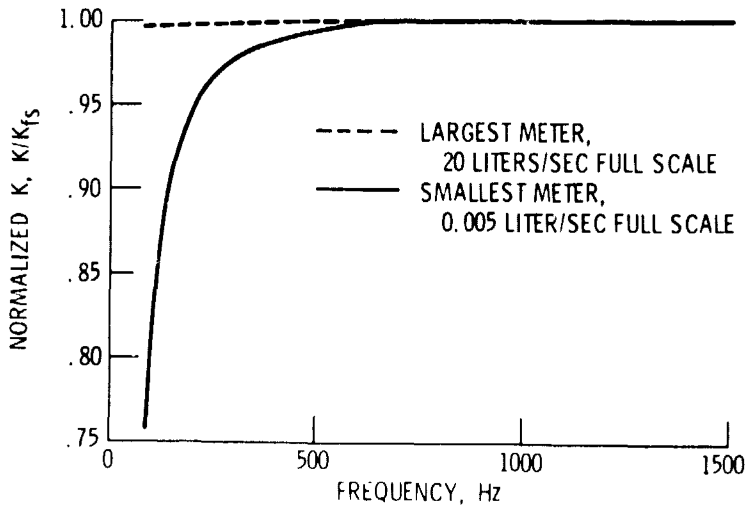

Figure 4. - Linearity of largest and smallest size meters.

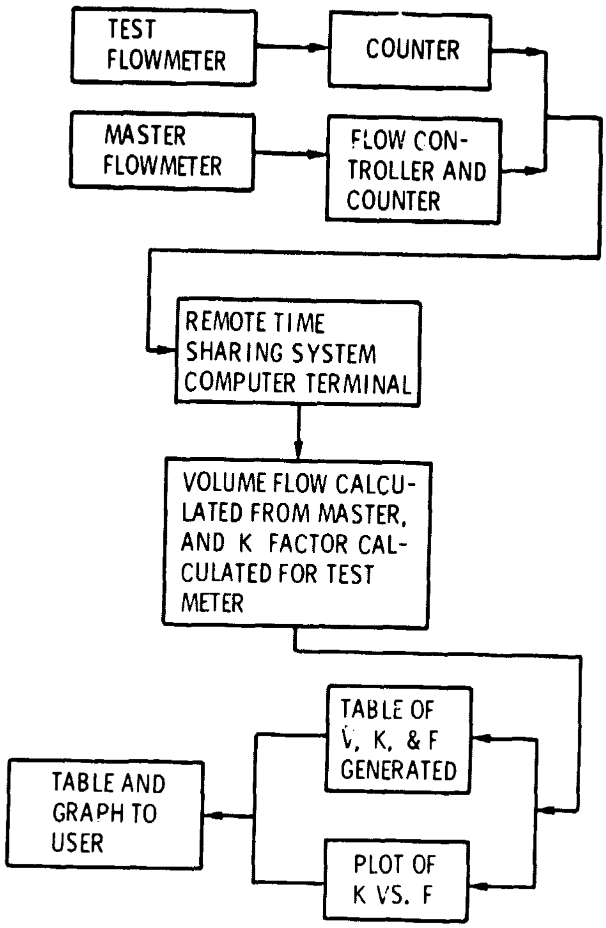

Figure 5. - Block diagram of data acquisition system.

DATE 01/15/76   MFG. XYZ CO.   S/N 1234   SIZE 3/4"

MODEL 76-001-3/4   J.O. YOD6606   FULL SCALE 20 GPM : 1500 HERTZ

FREQ.(HERTZ)	K PULSES/GAL.	Q GPM
1500.0	4367.6	20.6065
1400.0	4371.3	19.2163
1300.0	4370.6	17.8467
1200.0	4369.7	16.4770
1100.0	4374.7	15.0869
1000.0	4374.6	13.7155
900.0	4375.2	12.3424
800.0	4379.6	10.9599
700.0	4375.6	9.5986
600.0	4367.7	8.2423
500.0	4358.5	6.8831
400.0	4331.4	5.5410
300.0	4319.5	4.1672
200.0	4226.5	2.8392
120.0	4266.3	1.6876

Figure 6. - A typical table produced by computer.

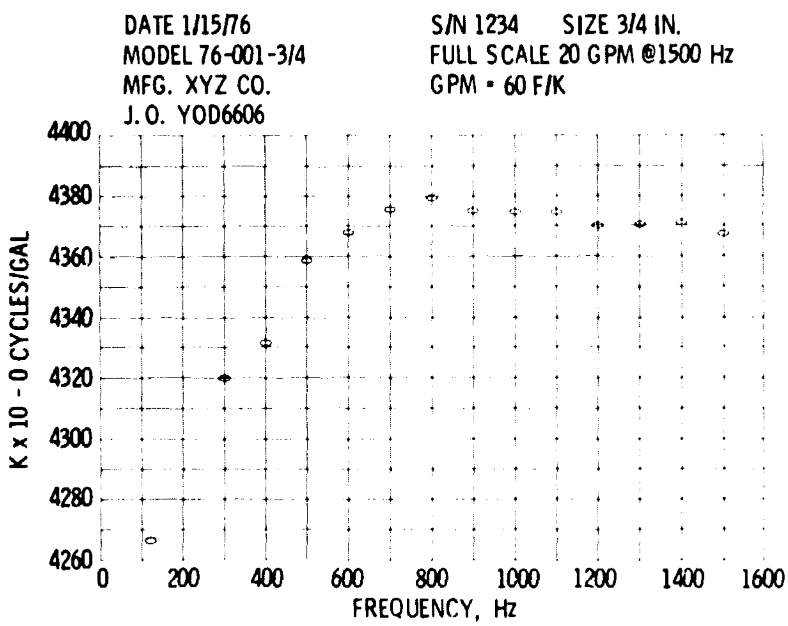

Figure 7. - A typical computer plot of a calibration curve. Numerals and plotted points have been enlarged for clarity.