Calibration of Tangential Paddlewheel Insertion Flowmeters

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ABSTRACT

This paper reports on efforts to calibrate flow sensors that are being used to monitor building thermal energy use in a large scale monitoring project. Several insertion-type paddlewheel meters are being tested with a dynamic-weight flowloop at varying flow velocities in pipe sizes ranging from 3 to 12 inches to establish their accuracy and metering characteristics. Preliminary tests indicate that some of the meters do not have the correct multiplying factor and as a result, indicate flow rates that are as much as 15% lower than the actual flow rates. However, when a corrected multiplier is applied the meters perform to within ± 5% of the flow rate. Preliminary tests also show that magnetic type paddlewheel meters may not be the best choice for flow rates below 2 ft/s.

These results have important implications for researchers using this type of meter. First, the discovery that some of the meters are not calibrated correctly reveals the need for independent calibration of this type. Second, the need to correct data that were taken using the incorrect multiplier has made it evident that there is a minimum of data that needs to be recorded from field installations. Specifically, both the fluid flow velocities and Btu measurements are required to make accurate adjustments to the thermal energy usage measurements. Finally, estimates of the fluid velocities should be determined prior to meter installation so that proper metering equipment can be installed in low-flow situations.

INTRODUCTION

In 1988 the Governor's Energy Office (GEO) of Texas received approval from the U.S. Department of Energy to establish a $98.6 million state-wide retrofit demonstration program, the LoanSTAR (Loan to Save Taxes and Resources) Program. The LoanSTAR Program was designed to demonstrate commercially available, energy efficient, retrofit technologies and techniques. Part of the approved DOE program includes monitoring buildings to determine the effectiveness of the retrofits. The monitoring for this program is composed of thermal metering (chilled and hot water Btu measurements), electrical load metering, psychrometric data (cooling and heating coil temperatures and humidities), and weather monitoring. All of the sensors and monitoring equipment must be calibrated prior to installation and recalibrated periodically while in service. For this purpose, a calibration facility was developed in which National Institute of Standards and Technology (NIST)-traceable instrumentation is maintained (Turner et al. 1992).

This paper discusses the procedures and results of the flowloop calibration facility used in calibrating the thermal monitoring equipment, namely the fluid flow sensors used in Btu measurements. The flowloop employed in this facility was completed in January 1991 and is dedicated completely to this project. The ultimate goal of the facility is to be able to test each flow sensor for calibration prior to installation and immediately following removal as well as to trouble-shoot faulty sensors. However, the early months of operation have been devoted to discovering and diagnosing unexpected problems that are inherent in any large scale metering operation (O'Neal et al. 1991).

Metering Approach

The thermal energy usage of the buildings in LoanSTAR is determined by monitoring the flow rates of the chilled and hot water mains and the corresponding entering and exiting water temperatures . For the LoanSTAR program, fluid flow meters already in place were used where possible but in the majority of the installations, new flow meters had to be installed. Even though the overall magnitude of the metering program is quite large, one of the difficult obstacles is obtaining reliable metering equipment for an entire building within the budget limitations. The flow metering devices could easily dominate the budget not only in initial costs, but also in installation costs. For this reason, insertion type tangential paddlewheel meters were chosen for the majority of the sites. These are relatively inexpensive ($200-500) meters and have manufacturers' claims of ± 1% (of full scale) accuracy which was determined to be adequate for the project requirements. Another added advantage is that the meters can be installed by means of a welded "hot tap" while the building remains in operation which greatly reduces installation costs.

Description of the Flowloop Facility

A liquid flowloop calibration facility was developed to compare the flow rate from a candidate sensor to the flow rate determined by a dynamic-weight tank. A diagram of the flowloop is given in Figure 1. The loop consists of two 10,000 gallon tanks, a series of four supply pumps, a test section and a return line and pump. The receiving tank platform rests on four symmetrically placed strain-bridge load cells. The dynamic weight of the water is measured over time by summing the signal from the four load cells and processing that signal with the water temperature to determine a volumetric flow rate. The test section holding the candidate meter links the two tanks and a perforated plate type flow straightener (Miller 1989) is installed at the supply end of this

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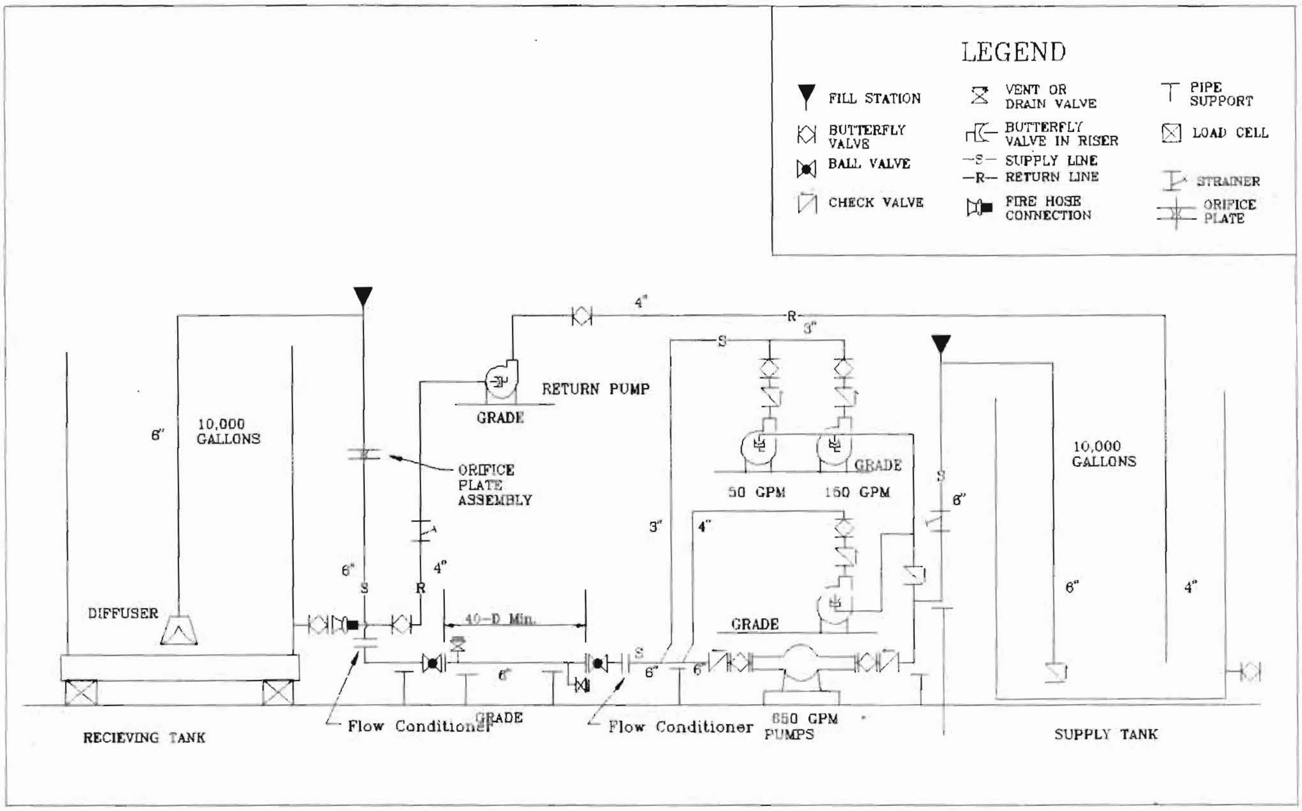


Figure 1: Diagram of the liquid flowloop Calibration Facility. This figure is a diagram of the flowloop that is used in the calibration of the flow sensors. Water at varying flow velocities is drawn from the supply tank, pumped through the test section and diffused into the receiving tank where the changing weight of the water is compared to the manufacturer's flow velocity.

section to ensure fully developed flow. Until recently, an ultrasonic flow meter was also installed in the test section to provide a secondary check to the load cells. An orifice plate assembly has now been installed to provide a secondary standard. Various flow rates are achieved by using combinations of four of the pumps located at the supply end of the test section. The test section is removable and varying pipe sizes can be installed ranging from 3" to 12" in diameter. Following each test, the water is pumped through a return line from the receiving tank back to the supply tank. Five orifice plates with different bore sizes can be interchanged to cover the full range of velocities.

The electronic signals from the load cells, candidate meter, ultrasonic meter, differential pressure transducer and temperature probe are converted into digital data through the use of a data acquisition system and a PC-based desktop computer. The signals from the load cells, ultrasonic meter and candidate meter are displayed in real time during the testing to alert the operator of any malfunctions during the test. On several occasions, unusual behavior has been identified that would not have been seen if the real time graphs were not employed.

Two types of insertion meter have been tested up to this point. The first is a magnetic tangential paddlewheel that generates a mV sine wave signal as it rotates. Each peak of the sine wave is registered as a separate pulse. The second type of meter is a non-magnetic tangential paddlewheel type. A constant DC signal is sent to the meter and as the paddle wheel rotates, the signal is broken by the passing blades. This signal break is detected as a pulse by the data acquisition system. In field installations, the signals are sent to thermal energy transducers (Btu meters) that combine the flow signal with the temperature difference information to output a thermal energy usage. In laboratory tests, the Btu meter was used only to monitor the flow rate.

RESULTS

Calibration testing has been completed for both types of meters in varying circumstances for a 6" pipe and an 8" pipe. In each case, the candidate flow meter was inserted into the PVC test section according to the manufacturer's specifications

Load Cells	Load Cells	Orifice Plate	Orifice Plate	Paddle-wheel	Paddle-wheel	PPG Factor	Reynolds Number
Velocity (ft/s)	CV= Sdev/Vel.	Velocity (ft/s)	CV= Sdev/Vel.	Velocity (ft/s)	CV= Sdev/Vel.	Empirically Derived	8" Pipe
0.269	10.98%	0.266	0.20%	*0.168	188%	9.1	20,900
0.463	8.66%	0.469	1.32%	*0.413	92%	13.4	35,900
0.502	5.78%	0.494	0.30%	*0.452	82%	13.2	38,900
0.592	5.62%	0.583	0.30%	*0.530	66%	13.7	45,900
1.314	4.57%	1.270	0.30%	1.305	26%	14.8	101,900
1.730	3.78%	1.696	0.60%	1.679	18%	14.5	134,200
2.127	1.42%	2.129	1.07%	2.067	17%	14.5	171,900
2.897	3.82%	2.868	1.12%	2.803	13%	14.5	224,700
3.344	3.72%	3.318	1.23%	3.294	11%	14.8	259,300
4.672	3.95%	4.654	1.60%	4.767	8%	15.3	362,300
5.838	4.43%	5.834	2.53%	5.933	6%	15.2	452,700
6.927	5.27%	**	**	7.107	7%	15.4	537,200
7.722	6.26%	**	**	7.971	8%	15.5	598,800

NOTE:

(*) While the paddlewheel did function at these flow rates, they are below those recommended by the manufacturer

(**) The flow rates are out of the range of the current orifice plate configuration.

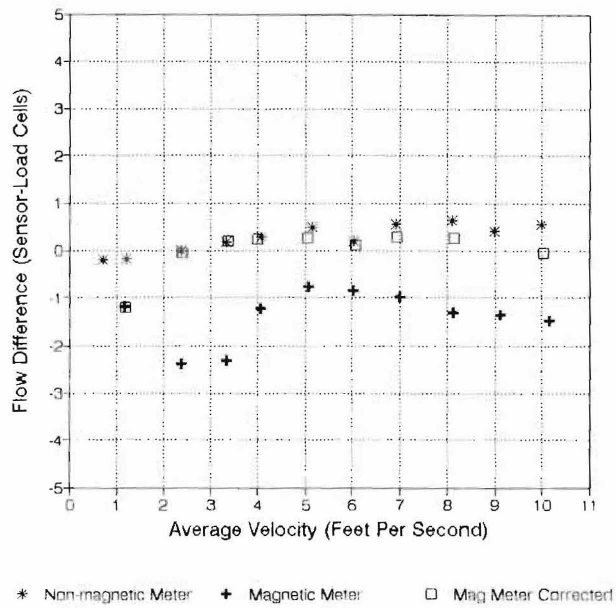
(+) The Reynolds number was calculated using load cell data.

Table 1: *Flow Velocities From a Test of Paddlewheel and Orifice Plates vs Load Cells.* This table contains data taken from a test of a non-magnetic insertion type paddlewheel. The meter was inserted at the manufacturers recommended depth of 1.5" into the flow stream of an 8" pipe. A PPG factor of 15 was used in this test as published by the manufacturer for these flow conditions. The PPG factor in column 7 is empericaIly derived during testing for comparison purposes.

and the output signal connected to the thermal energy transducer. The meters were then tested at flow velocities ranging from 0.5 ft/s to 10 ft/s in the 6" section and velocities of 0.5 ft/s to 8 ft/s in the 8" test section. A sample of the velocity data for a series of tests taken with the non-magnetic meter, load cells and orifice plates is presented in Table 1. Both the flow rate from the thermal energy transducer and the raw pulse signal from the flow meter were recorded with the data acquisition system. To determine the flow rate of the candidate sensor, the thermal energy transducer acts simply as a counter. It keeps track of the number of pulses received from the flow meter and uses a pulse per gallon (ppg) factor (determined from manufacturer's data) to calculate the number of gallons the flow meter has recorded. After the Btu meter has recorded a specified number of gallons, it sends a signal to the data acquisition system. The signals are then recorded over time to determine the candidate flow rate. In addition, the raw pulse signal from the flow meter is recorded. Dividing this number by the gallons registered by the load cells yields an empirically derived PPG factor which can then be compared to the manufacturer's published factor. The empirical factor varies slightly with the flow rate so an average value over the entire flow range is chosen and further tests completed with this new factor to determine the true performance of the meter.

The results from the magnetic paddlewheel in the 6" pipe showed the velocity measurements by the candidate sensor to be 15% low on average. In addition, the candidate flow rate went to zero for velocities below 2 ft/s. Several tests were run under these conditions and are presented in Figure 2. The failure of the meter below 2 ft/s confirmed the observations that had been made at some of the field installations. However, when the data were closely examined, it was discovered that the flow meter was still rotating and producing pulses but the strength of the pulses had dropped below the threshold of the Btu meter (subsequent tests showed that the threshold varies with the type of Btu meter). To remedy this, a pre-amplifier was inserted between the flow meter and the Btu meter and significantly improved the low flow results in the laboratory tests.

The manufacturer's PPG factor was about 15% higher than the one empirically derived during the testing which explains the low velocity readings. When the new PPG factor was entered into the Btu meter and the tests repeated, the results were significantly better. The results of these tests are presented in Figure 2. The meter with the corrected PPG factor comes within $\pm$ 5% of the flow rate for velocities above 2 ft/s. Results from the 8" pipe, presented in Figure 3, also indicated flow rates 15% lower than the load cell readings. In the 8" pipe, the low-end threshold for the magnetic meter was 2.4 ft/s.



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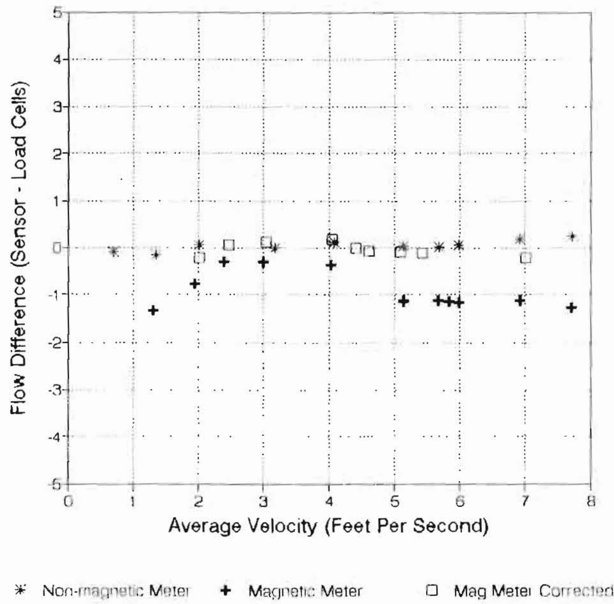

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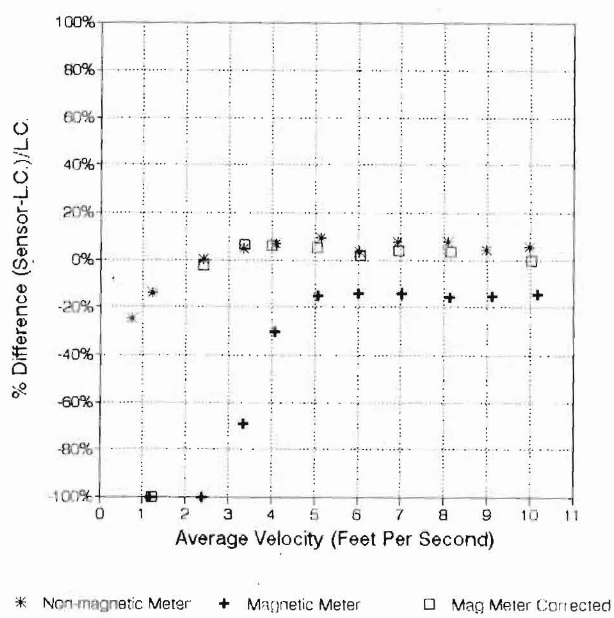

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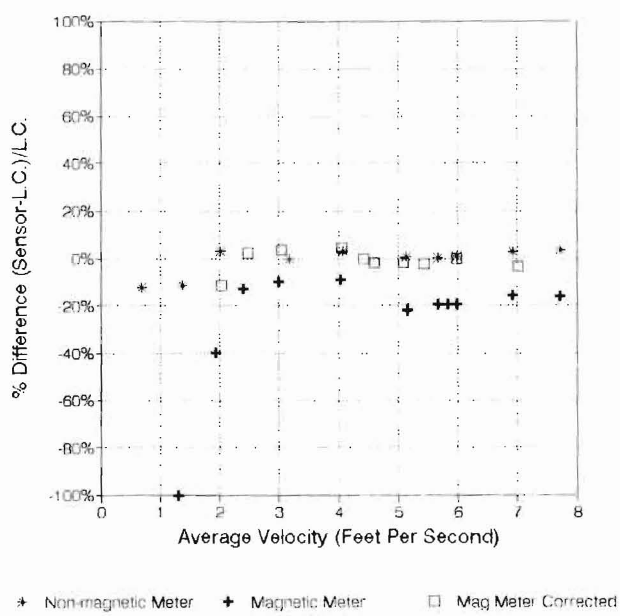


(3b)

Figure 2: *Test Results from the 6" pipe.* These results show the performance of the magnetic and non-magnetic meters with the manufacturer's PPG factor and the experimentally derived PPG factor.

Figure 3: *Test Results from the 8" pipe.* These results show the performance of the magnetic and non-magnetic meters with the manufacturer's PPG factor and the experimentally derived PPG factor.

For the magnetic paddlewheel, several items in addition to the routine tests were investigated. In the field installations, there are two different types of thermal energy transducer being used. Thus, the performance of the flow meter with each Btu meter was of interest. Also in the field, some meters are unable to be installed in a perfectly vertical position due to space limitations. Therefore, tests were run with the meter installed at different angles of rotation as seen in Figure 4. This set of tests also served to check the flowloop for any unsteady flow patterns that might be occurring.

The second Btu transducer yielded similar results to the first with the exception of the low end threshold. In this case, the signal from the magnetic flow meter was strong enough without a pre-amplifier to register flow rates in the 6" pipe as low as 0.8 ft/s but the accuracy trailed off considerably below 2 ft/s. To determine how much effect the insertion angle had on the flow rate output, the meter was tried in two different positions, 60 and 130 degrees from vertical. As seen from the results in Figure 5, there did not appear to be any appreciable difference between the performance of the flow meter in these conditions as compared to the normal insertion configuration.

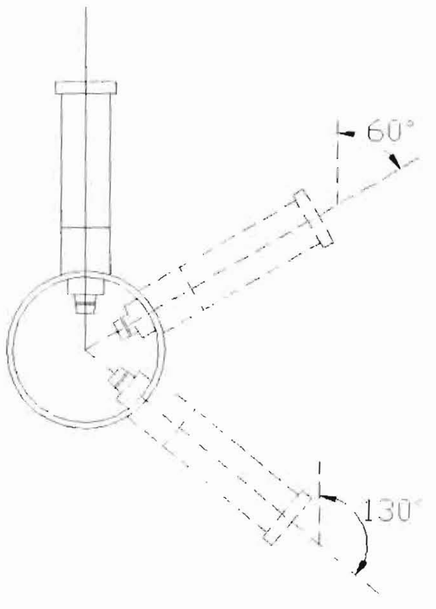
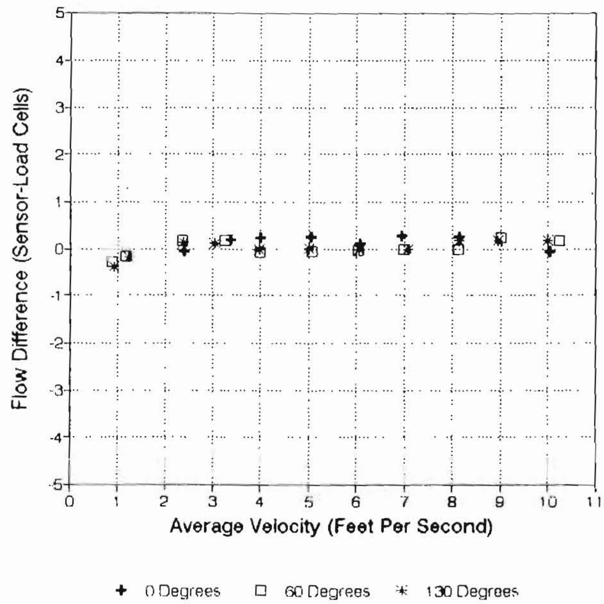
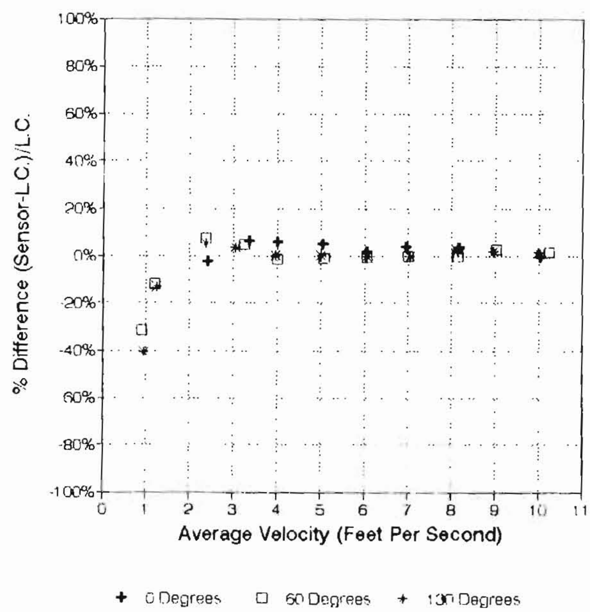


Figure 4: Cross section of the test section showing the rotation of the flow meter. The meter was rotated through 60 degrees and 130 degrees from the vertical.



(5a)



(5b)

Figure 5: Results from the rotation of the meter in the 6" line. These results are for the magnetic meter using the experimentally derived PPG factor.

The non-magnetic paddlewheel performed very well, especially in the low-flow range. First, the PPG factor provided by the manufacturer appears to be correct with the flow meter giving readings that are $\pm 5\%$ of the flow rate for the range above 2 fps and $\pm 10\%$ for the range of .5 to 1.8 ft/s. The second positive sign is that the meter continued to perform at flow rates below 1 ft/s. This is very encouraging because the project has several installations in which the flow rates are in this range (Haberl et al. 1992). Results from these tests are also presented in Figures 2-3.

DISCUSSION OF RESULTS

The results from the tests of the magnetic flow meter indicate that data recorded from field installations using these meters and the published PPG factor can be significantly improved. This is important because as many as thirty flow sensors were installed in the field prior to the completion of the calibration facility. Each one was using the manufacturer's recommended PPG factor. Because of the need for data adjustment, it has become apparent that it is important to record as much information from the BTU meters as possible. Some of the sites have recorded only the Btu usage and not the flow rate. This presents difficulty in post adjustment of the data from these sensors.

The results of the magnetic paddlewheel in the low-flow range verify what has been seen in some of the field installations. Since many of the buildings being monitored were designed as dual-duct, constant-volume systems and are now being retrofit to variable air volume systems, lower flow rates in the chilled water piping are quite common. There have been several instances where the meters quit working in these conditions. The pre-amplifier was field tested in some of these locations and showed a tendency of picking up 60 Hz background noise from mechanical rooms and sending it to the Btu meter. This distorts the accuracy of the flow signal considerably.

The results from the non-magnetic paddlewheel would imply that it is the better choice in low-flow applications. As a result, these meters are being put into use in situations where there are definite low flow circumstances. The magnetic paddlewheel meters still maintain a distinct advantage in price and are adequate in situations where flow is above their threshold. Thus, they are installed in locations that meet these criteria.

Projected Improvements

Several projects are in the works to improve the accuracy and capacity of the calibration facility. First, a variable speed drive capable of controlling any of the four supply pumps is almost ready for installation. It will enable any flow rate in the range to be obtained without the use of control valves. Second, a new data acquisition system is being employed. It is considerably more user-friendly and should speed up the testing process. It will also have the capability of controlling the variable speed drive. Finally, in addition to the 10" test section, a 6" clear test section has been built for flow visualization tests.

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