TELE-CALIBRATION OF GAS FLOW METERS

Pedro I. Espina

National Institute of Standards and Technology

Fluid Flow Group

Gaithersburg, Maryland

Abstract

At present, the paradigm used to deliver flow meter calibration services relies on the operation of in-house calibration facilities for providing metrology infrastructure. This approach has led to the construction and operation of many similar calibration facilities worldwide. The recent emergence and popularity of information technology offers an opportunity to change the way in which metrology services are provided to customers worldwide by enabling the use of existing calibration facilities by more than one metrology team.

This paper outlines efforts by the National Institute of Standards and Technology (NIST), the Colorado Engineering Experimental Station, Inc. (CEESI), and Daniel Instruments to develop the first gas flow tele-calibration facility in the world. The program seeks to make use of the high-speed information infrastructure of NIST's National Advanced Manufacturing Testbed to connect CEESI's Primary A volumetric calibration facility to the NIST Fluid Flow Group. The plan calls for modifications to the infrastructure of Primary A, which will enable tele-presence of NIST scientist during calibrations at CEESI.

It is expected, that in the future, the use of technologies similar to those described here will lead to the establishment of a “Calibration-Web” in which national laboratories, calibration laboratories, meter manufacturers, and end-users will be able to more efficiently share metrology resources to improve their competitiveness at a lower cost.

Introduction

Early last year, the NIST Fluid Flow Group was faced with the task of increasing the range of the Nation's flow standards. At present, NIST maintains primary gas flow standards that range from 0.0372 to 77,600 slm, using air as working fluid ($P_{max} \approx 20$ atm); or up to 1440 slm ($P_{max} \approx 60$ atm) using nitrogen, carbon dioxide, or argon.[1] US industry needs gas measurement traceability at much larger flow rates (ranging to approximately 100,000,000 slm), for a wide range of working pressures (from 1 to 60 atm), and a gamut of gas species. However, the construction of NIST facilities capable of handling such large flows is impractical due to capital and space constraints. A solution to this problem may lie in the small number of secondary metrology laboratories in the US that are capable of calibrating gas flow meters at these large flow rates. Unfortunately, these laboratories have no direct traceability to a US national flow standard, and thus the question becomes how to make these secondary metrology laboratories our national standards.

Any flow calibration facility classified as a NIST national standard undergoes rigorous evaluations that include the following elements. Initially, its performance characteristics are carefully evaluated to assess the total uncertainty of the facility. As part of this evaluation, the metrological environment used for testing meters is carefully studied to assure it provides ideal conditions during testing (*e.g.*, NIST evaluates the velocity profiles of its high Reynolds number facilities searching for deviations from ideal profiles). Once completed, the assessment is documented and subjected to peer review (see ref. 1 as an example). Subsequently, the individual sensors used by the facility are kept directly traceable to their corresponding national standard (*e.g.*, the NIST Thermometry Group regularly calibrates the Fluid Flow Group temperature transfer standard). Finally, for each and every test, NIST metrologists confirm that the procedures stated in the calibration report have been strictly followed during testing. Similarly, calibration facilities at a secondary metrology laboratory would be required to satisfy these elements if they were to be used as national standards. A new experimental concept known as tele-presence has the potential to enable calibration facilities anywhere in the US to be operated as NIST national flow standards.

Approach

NIST has a long tradition of achieving goals by taking advantage of the scientific diversity of its staff and by establishing partnerships with US industry. Following in this tradition, the Fluid Flow Group elicited the support of the Manufacturing Engineering Laboratory (MEL) which is the NIST branch that supports research in areas of machine control using IT. MEL has placed the resources of their National Advanced Manufacturing Testbed (NAMT, a program established to promote the use of IT for advanced manufacturing) at the disposition of the Fluid Flow Group. The NAMT has provided the Fluid Flow Group with Next-Generation-Internet/Internet II access which has enabled scientists to experiment with these new Internet technologies that are expected to be widely available in the US within the next five years. Additionally, MEL brought to the table expert support in tele-presence, sensor interfacing, and machine control. Using this broad base of talents and resources, NIST commenced its *Tele-Calibration of Gas Flow Meters* project[2] in May 1998, with the objective of demonstrating the feasibility of using IT to expand NIST's calibration services via tele-presence to US secondary metrology laboratories. The project seeks to remotely annex (via the Internet) primary gas flow calibration facilities located at secondary metrology laboratories to provide a framework for remote calibration, traceability, and accreditation of laboratories.

NIST has been fortunate enough to be joined in this experimental effort by the Colorado Engineering Experimental Station, Inc. (CEESI). The partnership with CEESI has provided NIST with a primary flow calibration facility, of the Pressure-Volume-Temperature-time (PVTt) type, capable of producing flow rates five times larger than those at NIST. In addition, CEESI has been willing to invest its own resources in the project, and the candidate facility (known as Primary A) shares many operational features with smaller PVTt systems at NIST. This common technology was very attractive given that it will facilitate the execution of the project by allowing in-house development of tele-presence applications at NIST's Maryland campus prior to transfer to CEESI's Colorado facilities.

With CEESI's Primary A selected as the demonstration site, the next item on the agenda was the development of an instrumentation/control/tele-presence architecture for the remote facility. Figure 1 shows the proposed tele-presence architecture, as it would be used in a generic PVTt facility. From left to right in the figure, a compressor is used to supply the gas needed by the calibration test, and a *digital flow control valve* is used to control output of the compressor. This digital valve is composed of a number of parallel sonic nozzles, each with twice the throat area of the previous one, that control the flow rate by opening different nozzle combinations. Following the digital valve, a long run of pipe (in excess of 100 diameters) helps establish fully developed flow to provide an ideal velocity profile to the meter under test (MUT). Prior to the MUT, a *flow assessment unit* is used to determine the quality of the flow entering the MUT (*i.e.*, velocity profile, pressure, and temperature). From the flow assessment unit, the gas flows through the MUT and is subsequently collected by a *flow determination system* (a PVTt system in Figure 1).

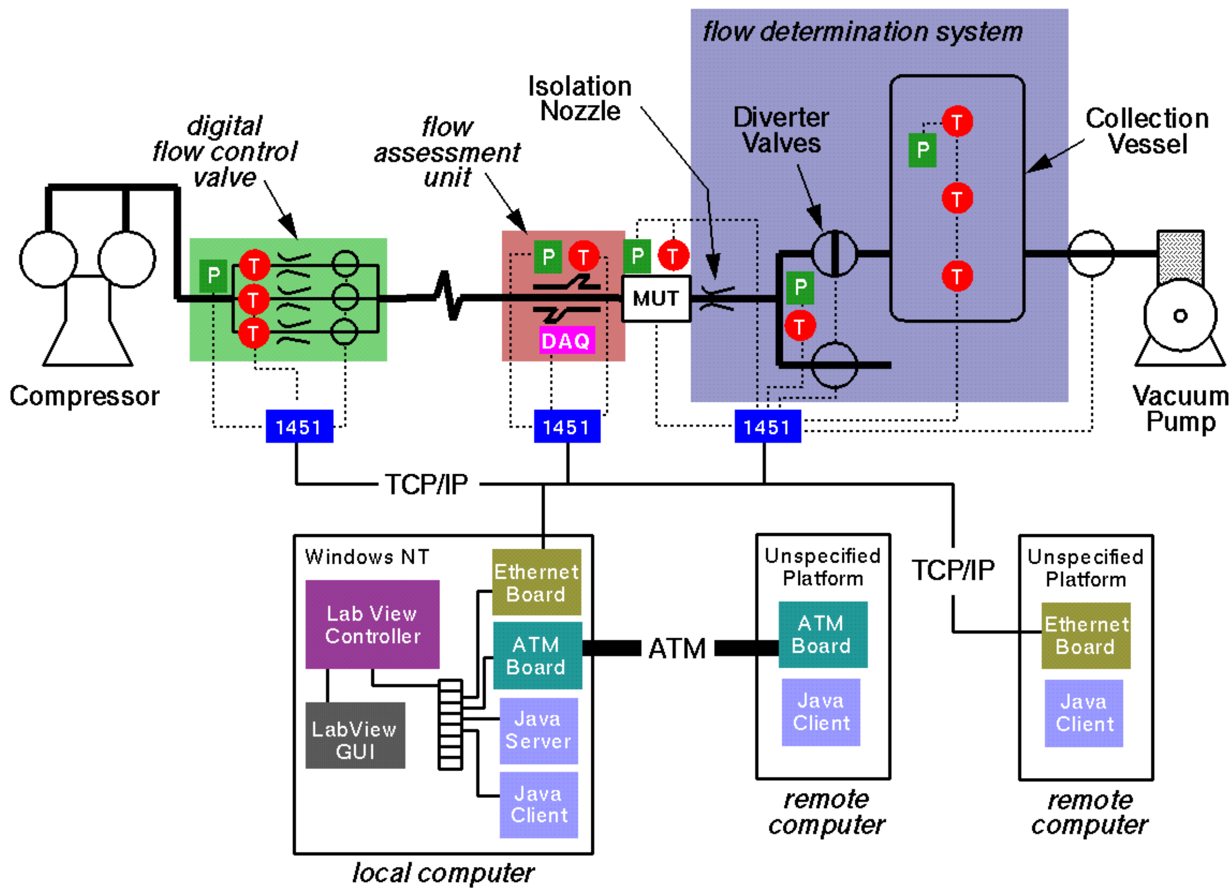

Figure 1. Tele-presence architecture as implemented in a PVTt calibration facility.

The use of a flow assessment unit to monitor the performance of equipment upstream of MUT constitutes a novel approach. For the Tele-Calibration project, NIST has consulted Daniel Industries for the development of an *advanced ultrasonic flow meter* (AUFM) to serve as part of the flow assessment unit. The AUFM will make use of an eleven-path ultrasonic transducer arrangement (see Figure 2) which was developed by NIST scientists using computer modeling of pipe flow fields and simulations of their corresponding ultrasonic signatures.[3] According to these simulations, the proposed sensor arrangement for the AUFM should have enhanced velocity profile diagnostic capabilities for deviations from non-ideal pipe flows. Interpreting the signals produced by the ultrasonic sensors will be a pattern recognition system capable of classifying the approaching unknown flow among one of a number of typically occurring flows contained in its electronic library. This electronic flow library (e.g., ideal pipe flow, elbow flow, reducer flow, etc.) will be initially created using results from computational fluid dynamics simulations, and later using actual experimental data. The extensive diagnostic capabilities of the flow assessment unit make it an additional asset to improve the quality of the calibration service provided by remote facilities.

Controlling the flow calibration facility described above is a *distributed-control* architecture based on the IEEE Std 1451.2-1997 smart sensor interfaces[4] (see Figure 1). These IEEE 1451 smart transducers are pocketsize, Ethernet based controllers (i.e., they communicate with other controllers using TCP/IP protocols) capable of communicating with many sensors at a time. Each IEEE 1451 comes equipped with its own microprocessor, which enables them to execute control, programs locally, thus relieving the local computer of some of its control tasks. In control architectures like the one described here, each IEEE 1451 is assigned its own IP address (*i.e.,* its unique Internet address), which enables them to appear as other computers in your control network. Because IEEE 1451 control networks are modular, they are easier to design, more flexible and reliable, and cost less than traditional *centralized-control* architectures where the local computer performs all tasks. The IEEE 1451 constitutes a new standard in sensor interface protocols, and as such, it is of great interest to NIST.

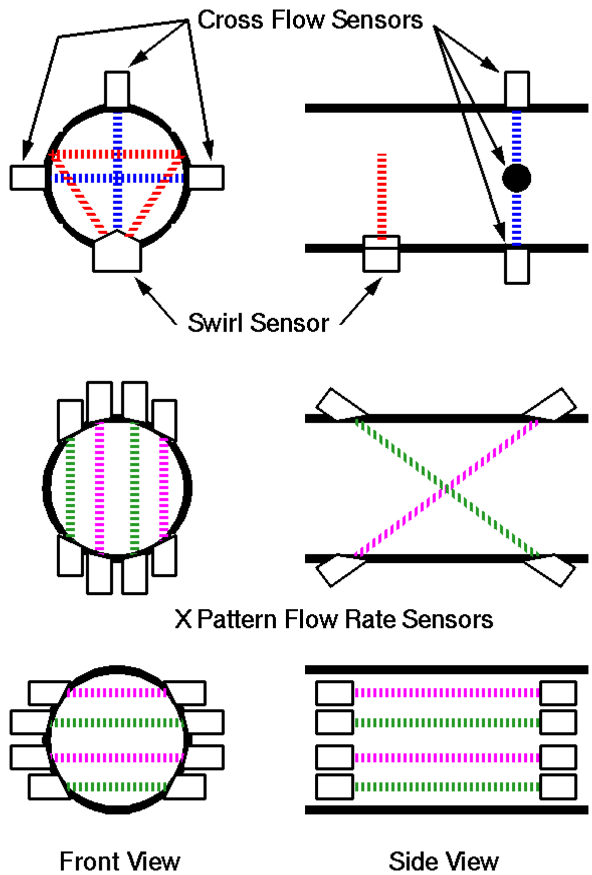

Figure 2. Schematic diagram of advanced ultrasonic flow meter (elements to be connected in series).

Delivering control tasks to the IEEE 1451's is the *local computer,* which for example, could be an off-the-shelf dual Pentium®II processor PC, running Windows NT®. This local computer communicates with the IEEE 1451 controllers via an Ethernet board, which in turn, is accessed by a data acquisition and control program (LabVIEW® in this example). During operation, the LabVIEW controller will be in charge of all the high level data-acquisition, control, and task scheduling. The operator will be able to access the Lab View controller in two different ways: using the conventional LabVIEW graphical user interface (GUI), or running a Java® client program in a web browser (*e.g.*, Netscape Navigator® or Microsoft Explorer®). Use of the LabVIEW GUI will allow the operator to rapidly modify the control program per the requirements of any particular calibration job. The Java client-web browser combination will enable remote access to the flow calibration facility by anyone having a connection to the Internet and a computer running a web browser.

Tele-presence in the flow calibration facility in Figure 1 is possible using two different IT media: today's Internet or tomorrow's Next-Generation-Internet/Internet II. Present day Internet is a *shared* media, which uses TCP/IP protocols to move information through it. When you make a request to the Internet, the information arriving at your computer is first sliced into small pieces, packeted using TCP/IP protocols, and then routed to you. Each one of the TCP/IP packets can travel to you via an infinite number of routes in the Web, each of which is decided at transmission time by the many Internet routers along the path. Once the packets arrive at your computer, the information is reassembled together and delivered to you. The disadvantage of this approach is that it can lead to very slow data transfer speeds, especially at times when the Web is overcrowded.

In contrast, the Next-Generation-Internet/Internet II is being designed as a *dedicated* media. When a request is made to the Next-Generation-Internet/Internet II, a number of virtual switches are thrown along its web and a point-to-point channel, of guaranteed capacity, is made available to you for as long as you have requested it. The information arriving at your computer is packeted using asynchronous-transmission-mode protocols (ATM) and directly sent to you. The advantage of this approach is that it can lead to very fast data transfer speeds, and of more importance, transmission time over this type of network is predictable.

The speed that ATM networks provide has many advantages for tele-presence applications. Real-time data, voice, and video can be simultaneously transmitted over ATM thus allowing full immersion in the remote site; real-time remote control of the flow calibrator is possible; and once the connection is established its capacity is guaranteed regardless the other use of the network. Given its performance characteristics, more industrial applications of ATM technology are expected as fiber-optic networks expand throughout the US.

Present Status and Future Plans

The Tele-Calibration project is in its infancy, but work is presently being conducted in many of the subsystems that are needed for implementation of the previously described architecture. In November of 1998, NIST and its partners held a tele-calibration workshop that was attended by a cross-section of the international flow metrology community. NIST, CEESI, Daniel, and the Air

Force Metrology Calibration Laboratory provided presentations, and guests were invited to participate in the effort. As a result, a number of parties have expressed their interest in bringing tele-presence capabilities to their daily operations.

By this fall, the project is scheduled to demonstrate the tele-calibration concept within the NIST campus using the local ATM fiber-optic network. In the year 2000, the technology will be transferred to CEESI for a cross-country demonstration by the fall of 2001. Meanwhile, other metrology laboratories will be provided with expertise for the implementation of their own tele-presence capabilities. In addition, NIST is actively seeking collaboration in this effort with other national metrology institutes to enhance our international standard comparisons program – so far, the response has been positive.

Disclaimer

Identification of specific commercial products is made for technical completeness but does not constitute an endorsement, nor does it indicate that the products are preferred for the application.

References

[1] J. D. Wright, and G. E. Mattingly, "NIST Calibration Services for Gas Flow Meters: Piston Prover and Bell Prover Gas Flow Facilities," NIST SP-250-49, Aug. 1998.

[2] www.nist.gov/tele-cals

[3] T. T. Yeh and G. E. Mattingly, "Computer Simulations of Ultrasonic Flow Meter Performance in Ideal and Non-Ideal Pipeflows," Proceedings of the 1997 ASME Fluids Engineering Division Summer Meeting (Vancouver, BC: ASME 1997), FEDSM97-3012.

[4] IEEE Std 1451.2-1997, Standard for A Smart Transducer Interface for Sensors and Actuators - Transducer to Microprocessor Communications Protocols and Transducer Electronic Data Sheet (TEDS) Formats, September 16, 1997, IEEE, Piscataway, NJ.