LRA, Vol. 10, pp. 107–111

Data Acquisition and Control for an Innovative Thermal Conductivity Apparatus Using LabVIEW® Virtual Instrument

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ABSTRACT: An innovative method and a novel research apparatus are being developed and tested to measure the thermal conductivity of non-Newtonian fluids while they are subjected to shearing flow. The emphasis here is given to the apparatus' instrumentation and computerized data acquisition and control, while a detailed description of the mechanical design and test results will be presented elsewhere. The measurement and control are accomplished and integrated by using a computerized data acquisition system and a comprehensive virtual instrument, developed using the LabVIEW® application software. In addition, this system allows for easy modification and enhancement of virtual (software) instrument by modification of the software program. © 1998 National Instruments. Published by John Wiley & Sons, Inc. Lab Robotics and Automation 10: 107–111, 1998

INTRODUCTION

Many unusual flow and heat-transfer phenomena associated with high molecular polymeric solutions and other rheologically complex non-Newtonian fluids are being investigated and offer great application potentials. It is known that these fluids are affected by shearing flow: becomes fiberlike, nonuniform, and nonisotropic. An innovative method and a novel research apparatus are being developed to measure the thermal conductivity of a fluid while it is subjected to shearing flow, thus measuring the thermal conductivity as a function of temperature and shearing parameters themselves [1–13]. This is contrary to the current state-of-the-art methods of measuring thermal conductivity under the condition of motionless fluid, to avoid convective heat-transfer influence on the results. The emphasis here is given to the apparatus' instrumentation and computerized data acquisition design and its demonstration as a purposeful and typical application example, while a detailed description of the mechanical design and test results are presented elsewhere [12, 13].

INNOVATIVE THERMAL CONDUCTIVITY APPARATUS AND INSTRUMENTATION

The apparatus (see Figures 1 and 2) consists of (1) an innovative, concentric-cylinders thermal conductivity cell; (2) a high-performance, variable controlled-voltage or controlled-current, DC power supply for the main heater; (3) two common, variable-voltage, AC power supplies for the guard heaters; (4) a variable-speed DC motor with drive and controller; (5) a constant temperature bath, controlled by a high-per-

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Laboratory Robotics and Automation

CCC 0895-7533/98/020107-05
Published by John Wiley & Sons, Inc.

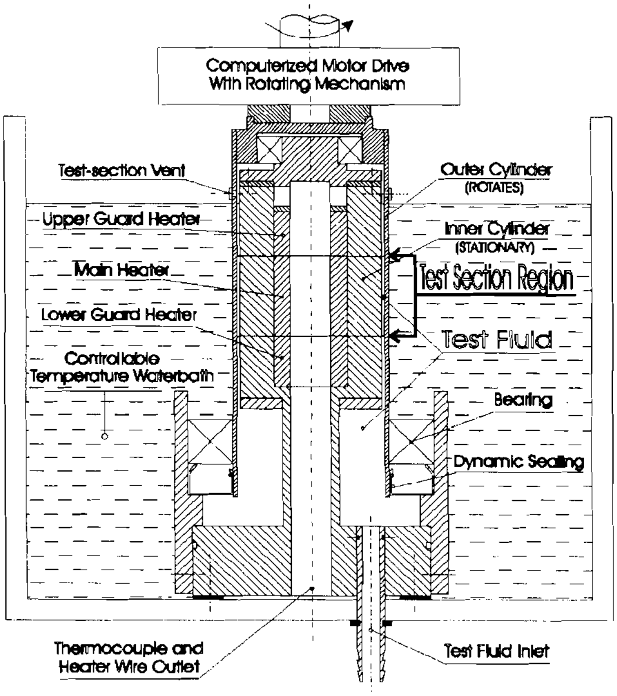


Figure 1. A novel thermal conductivity apparatus.

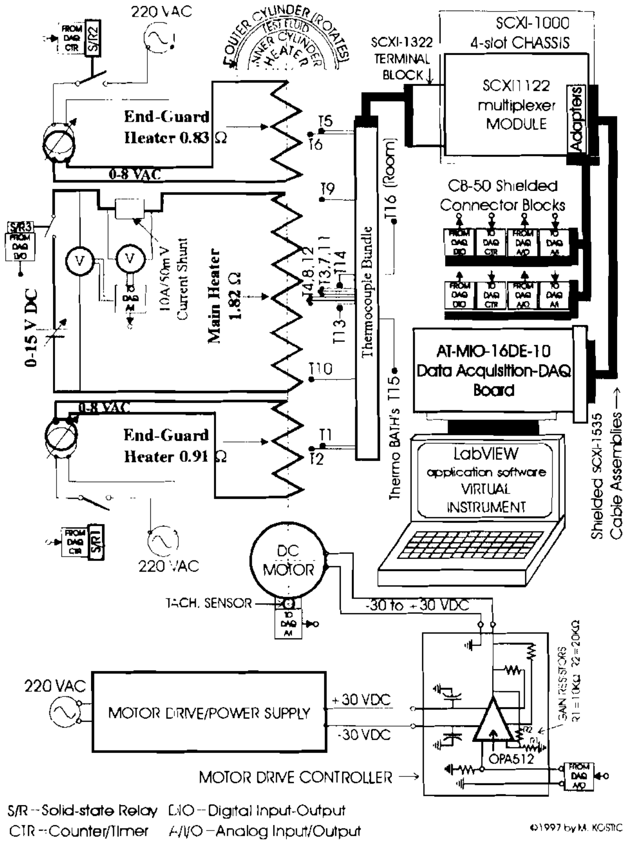


Figure 2. Schematic of instrumentation and data acquisition with control.

formance, digital immersion circulator; and (6) computerized data acquisition system with signal conditioning hardware. The measurement and control are accomplished and integrated by using a computerized data acquisition system and a comprehensive so-called "virtual instrument," developed using the LabVIEW® application software. The rotational speed is measured by a tachometer sensor and controlled by a voltage-varying DC motor through a built-in, solid-state, servo power-amplifier circuitry. The main heater is powered and controlled by a high-quality DC power supply, while two guard heaters are powered by common AC power supplies and controlled, including overheating protection, by the computerized system through solid-state relay switches. The computerized system hardware consists of a National Instruments AT-MIO-16DE-10 plug-in data acquisition board, shielded cable assemblies, and a signal conditioning module with a cold-junction compensated terminal block for thermocouple signals. Brief descriptions of selected important components and functions are given below and in the next section.

THERMAL CONDUCTIVITY CELL

The actual geometry of an apparatus and test fluid sample consists of a circumferential narrow gap (see Figure 1), similar to the apparatus for viscosity measurements [3, 4]. In addition, the appropriate heat-transfer flux in the transverse to test fluid flow direction is provided. The main test-section dimensions are 2.598 and 2.488 in., outer and inner cylinder diameters, respectively, with the 0.055 in. thick gap, filled with the test fluid in between. The inner cylinder's in-the-test-fluid immersion length is 3.8 in. It is heated by three 1.3-in. diameter electrical-resistance heaters, the central main heater with height 1.44 in., and the two remaining guard heaters of 0.78 in. high each. The inner cylinder with the heaters assembly is stationary, while the outer cylinder rotates (thus suppressing the Reynolds vortices) generating the Couette-type laminar flow of the test fluid. The two guard heaters are controlled in such a way to maintain uniform axial temperature in the central, main-heater region, so that the latter heat flux is virtually in the radial direction only. Due to absence of the test fluid's radial and axial velocities in the main-heater test-section region, the heat flux through the test fluid there is virtually transferred by conduction mode only. Thus, the measurement of the test fluid's thermal conductivity, while undergoing shearing flow, is achieved. More detailed description of the apparatus is given in reference [11, 12] and will be presented elsewhere [12].

INSTRUMENTATION AND MEASUREMENT

The required variables for thermal conductivity measurement are heat flux and temperature gradient through the test fluid, as well as the shearing rate of the test fluid. The apparatus' instrumentation is described next:

- The thermal conductivity apparatus is instrumented and equipped with 12 thermocouples imbedded in the inner cylinder at two different radial and five different axial locations (see Figure 2). In addition, a thermocouple is attached to the outside surface of the outer cylinder, at the center of the main heater's axial location. This thermocouple rotates with the outer cylinder and is terminated at its top end with a "quick" connector. Due to this special circumstance, the outer-cylinder temperature is measured after the steady state is achieved and after all other measurements are completed, by quick stopping of the cylinder rotation and with the "quick" connector wired to the data acquisition system. Then, one more measurement of all other temperatures is performed to confirm the agreement with the corresponding measurements just before the quick stop. In addition, the outside surface of the outer cylinder is measured during its rotation by a special thermocouple probe that rubs the surface under a slight pressure. The effect of rubbing is calibrated under different rotational and heating conditions. Due to the rotation of the outer cylinder, it is not known to the author if direct measurements of its temperature were done before. Two more thermocouples are used for measurement of constant temperature bath and room temperatures. All thermocouples are made from 30-gauge, T-type thermocouple wire and calibrated before and after assembly. These 16 thermocouples provide for the temperature gradient calculation needed for thermal conductivity measurement and, for confirming both, the unidirectional (radial only) heat flux through the test fluid and steady-state thermal condition.
- The heat flux is measured through measurement of the DC voltage drop across the main heater and a precise current resistor (shunt) (see Figure 2).
- Finally, the fluid shear rate is calculated using the known test-section geometry and the measured rotational speed of the cylinder with a calibrated tachometer sensor (see Figure 2).

All measurements are repeated until the kinematics and thermal equilibrium is achieved. After that, a number of final measurements are performed, and results are obtained using statistical analysis, as described elsewhere [12, 13].

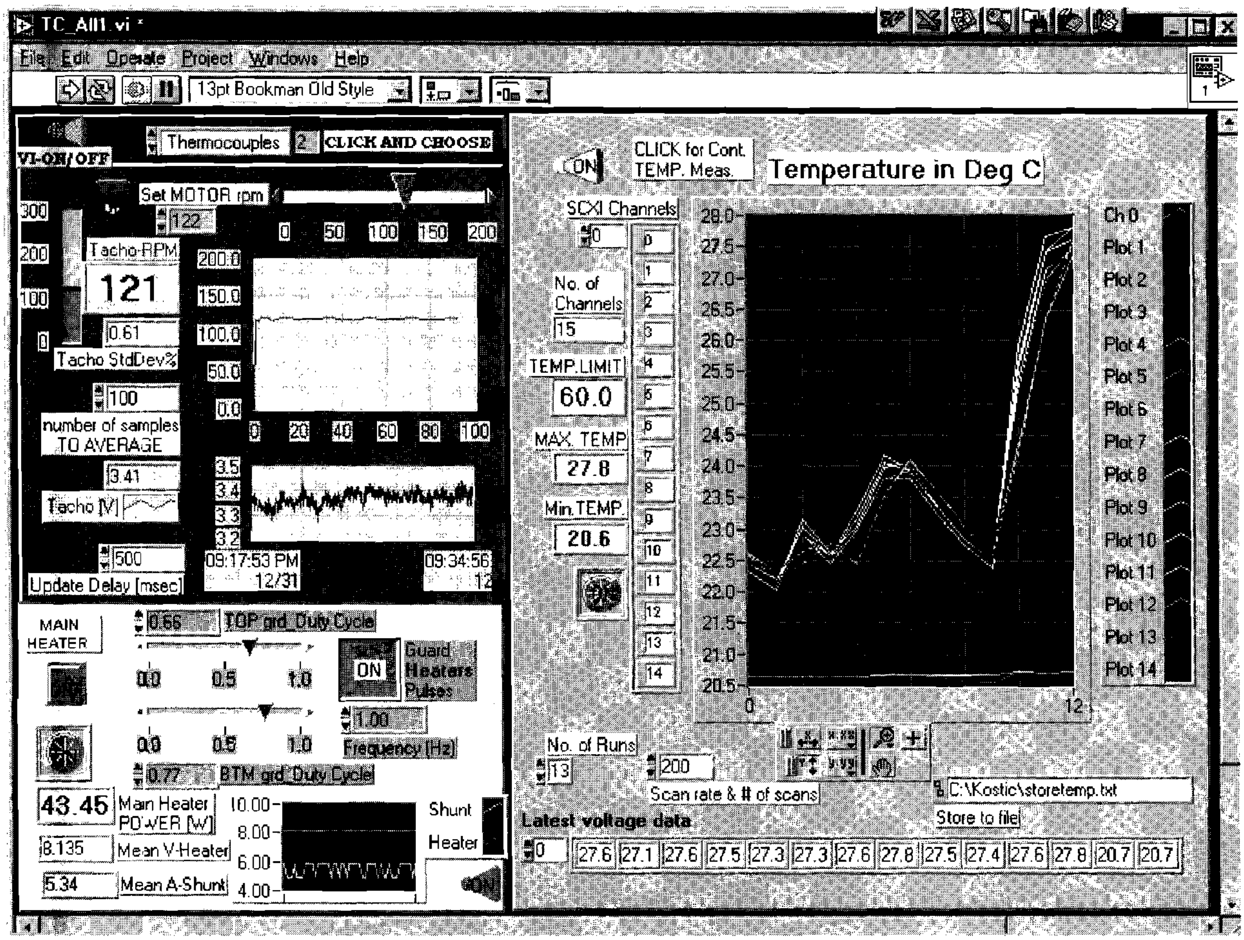
TEST FLUIDS AND RESULTS

Distilled water and the standard Newtonian fluids with known thermal conductivities are used for overall calibration of the apparatus. Then, the thermal conductivity of the following non-Newtonian fluids, suspected to have shear-rate–dependent thermal conductivity, will be measured as a function of shearing parameters: (a) aqueous solutions of polyacrylic acid (Carbopol); (b) aqueous solutions of polyacrylamide (Separan or Praestol); (c) aqueous solutions of carboxymethyl cellulose (CMC); and (d) aqueous solutions of polyethylene oxide (Poliox). At the time of writing, the apparatus, including the instrumentation and data acquisition as described next, has been completed, tested, and used for educational demonstration [11]. The calibration and initial test results are presented elsewhere [12, 13].

COMPUTERIZED DATA ACQUISITION AND LabVIEW VIRTUAL INSTRUMENT

Development and implementation of computerized data acquisition have the objectives of achieving more accurate measurement and interactive feedback control. The computerized data acquisition and control system is schematically presented in Figure 2. It consists of the following components made by National Instruments:

- AT-MIO-16DE-10 data acquisition (DAQ) board (E Series architecture, 100 k samples/s; 12-bit analog inputs, 16 single-ended/8 differential channels; two 12-bit analog outputs; two 24-bit, 20 MHz counter/timers; 32 digital I/O channels);
- SCXI-1000 4-slot signal conditioning chassis;
- SCXI-1122 16-channel isolated transducer multiplexer and signal conditioning module for thermocouple sensors;
- SCXI-1322 shielded terminal block;
- SCXI-1353 shielded cable assembly; and



Thermocouples 2

Set MOTOR rpm 122

Tacho-RPM 121

Tacho StdDev% 0.61

number of samples TO AVERAGE 100

Tacho [V] 3.41

Update Delay [msec] 500

MAIN HEATER

TOP grd Duty Cycle 0.66

Guard Heaters Pulses ON

Frequency [Hz] 1.00

BTM grd Duty Cycle 0.77

Main Heater POWER [W] 43.45

Mean V-Heater 8.135

Mean A-Shunt 5.34

Shunt Heater

CLICK for Cont. TEMP. Meas. ON

Temperature in Deg C

SCXI Channels 0

No. of Channels 15

TEMP.LIMIT 60.0

MAX. TEMP 27.8

Min.TEMP 20.6

No. of Runs 13

Scan rate & # of scans 200

C:\Kostic\storetemp.txt

Store to file

Latest voltage data 0 27.6 27.1 27.6 27.5 27.3 27.3 27.6 27.8 27.5 27.4 27.6 27.8 20.7 20.7

Figure 3. LabVIEW virtual instrument front-panel interface.

- two CB-50 terminal blocks with short NB-1 ribbon cables attached to appropriate SCXI-1353 assembly adapters for analog and digital input/output and counter/timer connections.

A so-called "virtual instrument" is developed, using the LabVIEW software application program. It integrates measurements, data acquisition, and interactive data processing and analysis for the feedback control and the data and results display. The LabVIEW "virtual instrument's front-panel" interface is given in Figure 3. It provides for accurate and interactive control and display of measured and analyzed variables for three major functions: (1) motor's rotation, (2) guard heaters' control and main-heater power measurements, and (3) temperature measurements and overheating protection. The measured variables are displayed graphically, along with their average values, standard deviations, and limits if appropriate (see Figure 3). The control of all functions and data acquisition settings is conveniently provided through the virtual instrument's front-panel interface. The measured data are also stored in a file for future processing. The algorithm of the LabVIEW virtual instrument software program is presented elsewhere [11]. The measurement and process controls are enhanced by (see Figures 2 and 3) the following:

- implementing a feedback control circuit via DAQ AO signal for DC motor drive using a calibrated tachometer sensor's DAQ AI signal;
- efficient and accurate feedback control of guard heaters' power by varying the "duty cycles" of DAQ Counter/Timer (CTR) pulse signals to control the corresponding solid-state relays (S/R);
- comprehensive overheating protection control by switching off the solid-state relays if and when needed;
- interactive and comprehensive monitoring for the kinematics (via DAQ AI tachometer signal) and thermal steadiness (via SCXI-DAQ thermocouple signals) of all processes; and

- convenience of increasing the number of thermocouple sensors (by implementing the SCXI module and terminal) for more advanced measurements of temperature and heat fluxes.

In addition to the research objectives, this apparatus is enhanced with appropriate documentation and labeling to be used as a typical and elaborate application for educational demonstration in Engineering Experimental Methods I and II courses (MEE 390 and 490) at the Mechanical Engineering Department of Northern Illinois University. The basics of LabVIEW software are taught in these courses, and students have used this apparatus as a purposeful application for demonstration of computerized instrumentation and data acquisition for interactive measurements and control.

CONCLUSION

One of the objectives of this project is to utilize the latest powerful, yet inexpensive, technological developments (sensors and transducers, data acquisition and control integrated boards, computers, and application software) for research and teaching by example. The designed, computerized measurement and data acquisition system accomplishes the following objectives:

- acquire measured data with high speed and accuracy;
- interactively process and analyze measured data for immediate use or future postprocessing;
- provide interactive and accurate feedback process control—motor speed and guard-heating power; and
- interactively displays the raw/measured and processed/analyzed data in graphical and numerical forms.

In addition, such a system allows for easy modification and enhancement of the so-called virtual (software) instrument by modification of the software program. It is important to emphasize that functionality and quality of a virtual instrument is practically limited by our creativity.

ACKNOWLEDGMENTS

The author acknowledges support by the Department of Mechanical Engineering and Graduate School of Northern Illinois University and National Science Foundation support (Grant No. CTS-9523519). The author is also grateful for help in mechanical design and fabrication to Mr. Haibo Tong, graduate student, and Mr. Al Metzger, instrument maker and technician supervisor, as well as for help in electronics design and fabrication to Mr. Bill Vickers, senior electronics technician.

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