INTERNET-CONTROLLABLE VORTEX TUBE EXPERIMENTS FOR THERMODYNAMICS LABORATORY CLASSES

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Abstract

The purpose of this paper is to present the developmental work at Drexel University where the thermodynamics laboratory is controlled and monitored through the web interface. The thermodynamics course is an integral part of the undergraduate engineering program as well as the engineering technology program at Drexel University. The enhanced understanding of principles and theories of thermodynamics can be attained through carefully designed lab experiments. However, the enrollment in thermodynamics courses typically range anywhere between 30 to 70 students, while there is only one thermodynamics laboratory in the college. This situation hinders the students' access to the lab and, consequently, not every student has enough time to complete the experiments. To counter this problem, the Internet-controllable thermodynamics laboratory has been developed in the Goodwin College of Drexel University. With the use of Internet, sensors, network camera and various LabView tools, students can test, control, monitor and study the operation of a vortex tube and its underlying principles from anywhere, anytime. Initial comments from the students show that this lab is expected to provide greater flexibility, especially to those who have scheduling conflicts during the regular class hours.

Keywords: vortex tube experiment, online laboratory, LabView, thermodynamics

Introduction

Over the last decade, web-based education has become commonplace among colleges and universities[1]. Nationwide, in 2001, 90% of public institutions offered distance-education courses and over 1.6 M students took at least one of these courses[2]. Recently, universities across the nation began offering web-based lab courses where the workings of equipment can be observed and controlled in real-time over the Internet[3-6]. Online laboratories allow multiple institutions to share expensive lab resources while providing convenience and flexibility to students with scheduling conflicts[7-14]. At the same time, U.S. colleges and universities are challenged to contain and even reduce the technology costs while responding to the expectations of the "New Millennial Generation" to upgrade educational systems. One suggestion is to focus on new and innovative models for facilitating collaboration. The benefits of remote laboratories range from defined and anticipated to unexpected and extensive[15]. In a global scope, this concept holds enormous potential for mitigating the limitations of single academic programs, the resource constraints to support laboratory modernization, and the difficulties in duplicating expensive lab facilities at multiple locations by allowing the sharing of lab equipment. The basic idea behind using the Internet is "you will never be far away from the laboratory" with access to the laboratory from anywhere, anytime. Such setting provides, in some cases, more effective learning because students can adjust their pace according to their learning ability.

Internet-based education can be viewed as a form of e-learning or blended learning. Blended learning means a complement of on-line education using various media, or off-line education by on-line discussions, thus enabling various new educational strategies. Many Internet-based tools and educational programs, however, limit students' ability to understand engineering principles since they are mostly visual-aid tools and do not necessarily simulate real workings of lab components[16]. A similar situation arises in mechanical engineering education where simple simulations or computation tools are provided in lieu of actual lab equipment. Such practices are inadequate for mechanical engineering education, especially when workings of laboratory components are simulated through a highly simplified graphical representation. Another problem is the high number of students enrolled in fundamental engineering courses, such as thermodynamics. In any given academic terms, the number of students in a thermodynamics class range from 30 to 70, while there is only one thermodynamics laboratory for the students. The limited access to the laboratory greatly shortens the time that each student can work in the lab, which has been a hindrance to students' learning. To counter this problem, while providing more time to students who have scheduling conflicts during the regular class hours, the Internet-controllable thermodynamics laboratory has been developed at Drexel University. Currently, a vortex tube assembly is connected to the Internet through the LabView software. However, other components in thermodynamics lab will be added to the network as the development continues. Students can now remotely conduct experiments from anywhere, anytime, and spend as much time as they need until they fully understand the principles on a particular set of subject matters. It is expected that this laboratory provides greater flexibility and improved learning effectiveness for students.

Laboratory Development

This section elaborates on the detailed components of the web-enabled laboratory, and provides graphical illustrations on the system architecture. The experimental setup for the Internet-controllable vortex tube consists of:

- Source of compressed air (5HP electric compressor and air dryer unit)
- Pressure sensors (Omega Dyne Inc; Model: PX209-200A5V)
- Temperature sensors (Omega Engineering Inc; Model: TX91A-K2)
- Vortex Tube
- National Instrument-DAQ card (16 inputs, 16 bits, 200KS/s, Multifunction I/O for USB)
- LabView software
- Server (Host Computer, IP Address: 144.118.xx.xxx)
- Client (PC downloaded with LabView Runtime Engine)
- Network IP Camera (Toshiba, Model: IK-WB21A with 22 x optical zoom, pan, tilt features)
- Flow Sensor/Controller (Mass flow controller: FMA 5400/5500 Omega and control valve).

A vortex tube is an instrument that separates a compressed gas supply into streams of gas at different temperatures. One stream is colder and the other is hotter than the temperature of the supply. The vortex tube has no moving parts. When compressed air is introduced into the vortex tube, and passes through the vortex generator inside, one end of the vortex tube generates hot air, while the other end generates cold air (Figure 1). A valve in the hot air outlet controls the volume and temperature of air released from the cold end. The vortex generator, which is a stationary part, regulates the volume of incoming air in order to alter the air flows and temperature ranges[17, 18].

In this experiment with the vortex tube, the first and second laws of thermodynamics are observed. The first law states that the energy cannot be created or destroyed. Instead, the amount of energy lost in a steady state process cannot be greater than the amount of energy gained[17, 18]. The second law states that energy systems have a tendency to increase their entropy (heat transformation content) rather than decrease it[17, 18]. The second law is an expression of the fact that, over time, differences in temperature, pressure, and density tend to even out in a physical system. Entropy is a measure of how far this even-out process is progressing[19]. To conduct the analysis, the volume (flow rate) of the air supplying the vortex tube is controlled and monitored by measuring the flow in the hot and cold streams leaving the vortex tube. The temperature and pressure are also monitored. Data acquisition for various incremental flow rates are captured using LabView and statistical data analysis is applied to thermodynamic equations to verify the first and second laws.

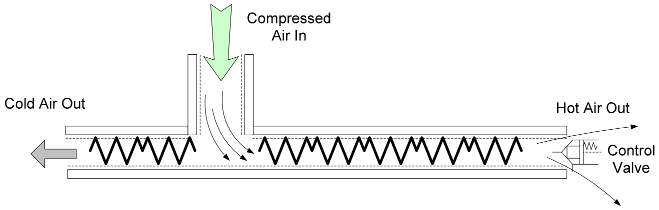


Figure 1. Schematic representation of vortex tube.

In the setup, thermocouples are used as temperature sensors. The low-cost TX91A temperature transmitters convert thermocouple or resistance temperature detection (RTD) signals into a 4 - 20 mA dc signal output that is directly referenced to the mV input. The TX91A transmitters mount directly within OMEGA’s standard protection heads for connection to the sensor [20]. They accept J, K, T, E thermocouple or 100 Ohm platinum RTD Inputs with their storage temperature range being -46 to 121°C (-50 to 250°F)[20]. The transmitter accomplishes cold reference junction compensation and signal regeneration. The stream of gas entering the mass flow transducer is split by shunting a small portion of the flow through a capillary stainless steel sensor tube. The remainder of the gas flows through the primary flow conduit. The geometry of the primary conduit and the sensor tube are designed to ensure laminar flow in each branch[21].

According to the principles of fluid dynamics, the flow rates of a gas in two laminar flow conduits are proportional to one another. Therefore, the flow rates measured in the sensor tube are directly proportional to the total flow through the transducer. In order to sense the flow in the sensor tube, heat flux is introduced at two sections of the sensor tube by means of precision wound heater-sensor coils. Heat is transferred through the thin wall of the sensor tube to the gas flowing inside. As the gas starts to flow, heat is carried by the gas stream from the upstream coil to the downstream coil windings. The resultant temperature-dependent resistance differential is detected by the electronic control circuit[21]. The measured gradient at the sensor windings is linearly proportional to the instantaneous rate of flow taking place. An output signal is generated that is a function of the amount of heat carried by the gases to indicate mass and molecular-based flow rates. FMA 5400/5500 mass flow controller series incorporates a proportionate solenoid valve and a motorized valve. The closed loop control circuit of the FMA 5400/5500 continuously compares the mass flow output with the selected flow rate. Deviations from the set point are corrected by compensating valve adjustments, hence maintaining the desired flow parameters[21]. Figure 2 illustrates the overall setup.

To conduct the experiments, the compressed air is transferred through the vortex tube, which gives different air compression at both ends. This in turn creates differences in temperature. At a colder end, the temperature goes on decreasing and at a hotter end, the temperature goes on increasing with the change of air flow. Also, pressure change is measured, recorded and displayed. The NI-DAQPad 6015 is used to collect data from the setup. The National Instruments DAQPad-6015 is designed specifically for mobile or space-constrained applications. Plug-and-play installation minimizes the configuration and setup time, while direct screw-terminal connectivity simplifies signal connections (see Figures 3, 4 & 5).

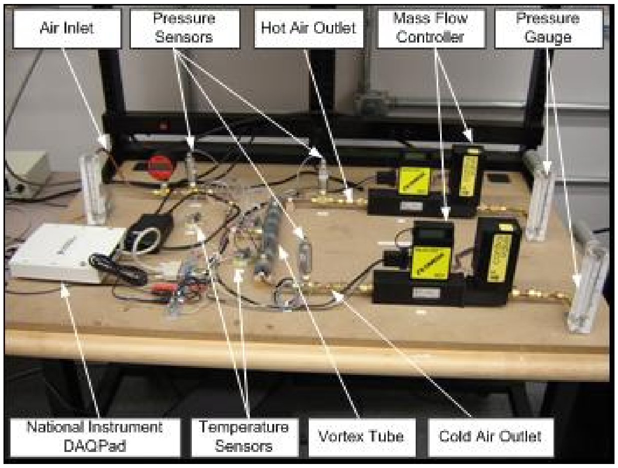


Figure 2. Setup of Internet-controllable vortex tube experiment.

NI-DAQmx provides a seamless interface to LabVIEW, environments with features such as DAQ Assistant, and a single programming interface for all device functions [22]. A program is written in LabVIEW and the data are monitored and stored in an LVM file. The NI-DAQPad is connected to the server through the Drexel LAN with an IP Address-144.118.xx.xxx. A client PC and the network camera are also connected to the LAN. The host computer connected to the NI-DAQ Pad acts as a server.

The data acquired is displayed in both tabular and visual formats. In order to make the LabView program available on the Web, "Labview Web Publishing Tool" is used. The server not only monitors, records, but also transfers the control functions to the clients so that students working online can view, record and control the different parameters, while conducting the experiments. The "LabVIEW Run-Time Engine" can load and run any LabVIEW Virtual Instruments (VIs). It is a stand alone program in a sense that you do not need to have LabVIEW installed on your PC to run Virtual Instruments. The "LabVIEW Run-time Engine Version 7.1 for Windows 2000/NT/XP" is used to make the VIs available through a Web browser. The Run-Time Engine also allows the browser to display the VIs that is embedded in the web page. This also enables the remote control and monitoring of parameters, such as flow, temperature and pressure.

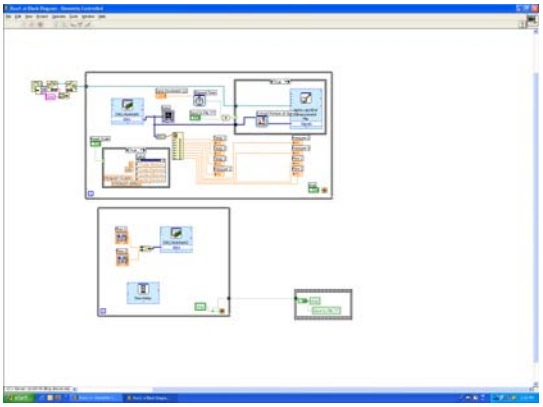


Figure 3. Block Diagram of vortex tube setup using LabView.

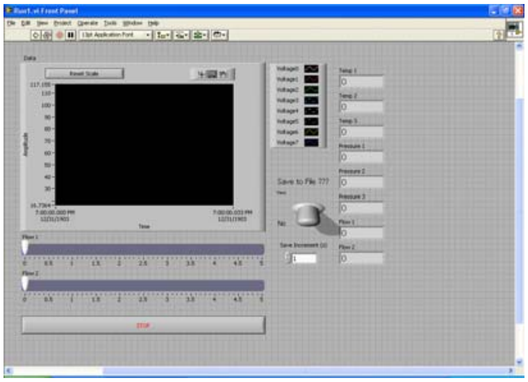


Figure 4. Front Panel using LabView to measure thermodynamic parameters on Server side.

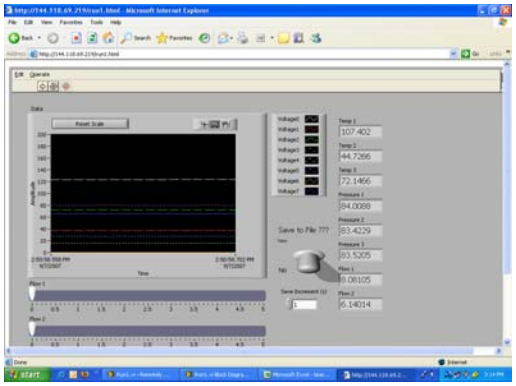


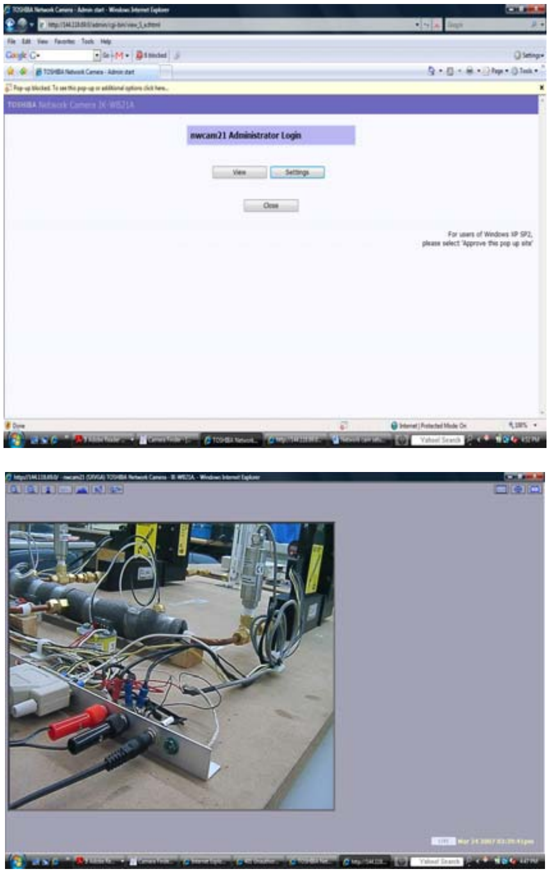
Figure 5. Remotely monitored and controlled through web-browser using LabView on client side.

In order to properly perceive and understand the workings of the remotely located laboratory, an adequate form of visual & auditory feedback is required. The IK-WB21A Toshiba network camera is used to deliver video steams and sound in real-time through the Internet. The camera is equipped with Ethernet (RJ-45) 10Base-T/100Base-TX network interfaces. The camera interface is web-enabled so that students can view all the hardware components online. A built-in pan (left/right) and tilt (up/down) mechanism enables users to change the direction of camera lens. The camera has a magnification of up to 22 times (optical zoom), hence students can zoom in onto any specific components of the setup. The camera also comes with scan, presets, auto patrol and various other monitoring features.

A high-resolution picture element (a progressive CCD sensor) in the camera generates pictures of 1280 (H) x 960 (V) pixels. Therefore, the live images at the client side are clear and bright (Figure 6). Students can also listen to the sound as the pressure or air flow rate changes during the experiments. The sound is transferred from the built-in microphone in the camera. The visual and auditory feedback from the remote experimental setup provides enhanced realism to the students. In fact, tele-operation requires much mental effort, as opposed to the direct method, due to the limited ability of sensors to provide a complete and accurate view of reality[23]. In tele-operations, the overall effectiveness of the tasks can be significantly improved when visual cues are combined with sound, which further reduces the mental effort [24-27]. The acoustic signature emitted from the working components carries a multitude of information, such as the speed of actuators and the strain of hardware components under loading conditions. Stereo sound is important to sense the direction of approach and exit, which is critical to prevent injury or collision of equipment. Since there are no moving parts in the setup, the provision of stereo sound is less critical.

Experimental Results and Concluding Remarks

During the fall and winter terms of 2007 academic year, the online vortex tube experiments were conducted by those students enrolled in the MHT 205 Thermo Dynamics I course, Goodwin College of Professional Studies, at Drexel University. Students were first brought into the lab where the setup resides and had time to get acquainted with the working principles of the equipment. Later, they were given a lab report that requires the online vortex tube experiments. Initial students' response was very positive. Most students found that the online operation was convenient and highly intuitive to use. However, some students still prefer having an instructor present, due to the apprehension of "what if something goes wrong." Also, students claimed that more detailed lab instructions would be helpful in conducting the experiments. In a nutshell, the online experiment result shows that the laws of thermodynamics are verified. The output was examined in terms of changing temperature, pressure and air flow. Using the thermocouples and the vortex tube, it was observed that the temperature at a hot end increases to a maximum value, while the



For users of Windows XP SP2, please select 'Approve this pop up site'

Figure 6. Remote visualization of setup using network camera.

temperature at a cold end decreases to a minimum value. During the experiment, statistical data are captured through LabView and the various parameter deviations are observed (see Figure 7).

Overall, the online experiments provided interesting insights as to how to offer effective lab courses over the Internet. Even though the technologically advanced systems present seamless web accessibility, the specifics in tele-operations in line with the accompanying instructions multiply the complexity in creating a pedagogically effective online lab course. The absence of teachers, isolation of students, and the lack of detailed lab instructions, seem to present much more significant difficulties in online lab courses than the audio/visual modalities and the types of user interface. However, it is conceivable that the Internet-based educational tools are becoming more and more prevalent in mechanical engineering and technology education, due to the convenience and flexibility.

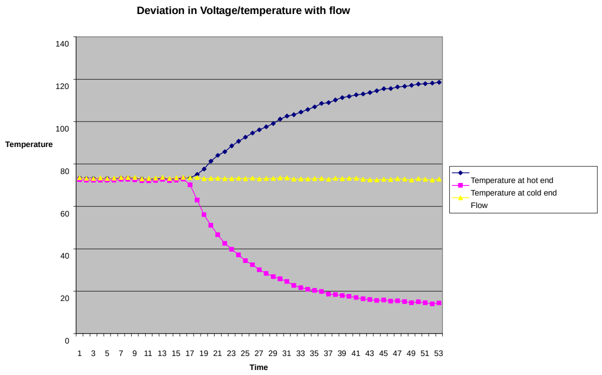


Figure 7. Chart for data Acquisition using NI-DAQ pad.

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