Renovating a Mechanics of Materials Laboratory using Data Acquisition and LabVIEW

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Abstract

This paper will describe how an existing tension test experiment was renovated and how two new experiments involving planar trusses were introduced into the core mechanics of materials laboratory at The University of Tennessee at Chattanooga (UTC). The renovation of the tension test involved the purchase of an electronic extensometer and pressure sensor for our 30-year-old Tinius Olsen (TO) machine. Also, appropriate data acquisition boards and signal conditioning modules were purchased and installed on the TO machine. The TO renovation was completed as a master's project. One of the new truss experiments, a cantilever system, was manufactured in the mechanical shop at UTC. The material selection of aluminum, sizing of the truss members, installation of the truss in a frame, the application of the strain gage on the truss members and the design of the LabVIEW program was performed as a design project in our ENGR 447 – Senior Mechanical Engineering Laboratory. The other new truss experiment, a roof truss system, was purchased from HiTech Scientific. The purchase consisted of a steel truss, its supports, the mounted strain gages with lead wires, and the load (proving) ring. A design group from ENGR 447 also created the LabVIEW program for this truss. Both new truss experiments required a new 8-channel strain gage amplifier and conditioner that was purchased from Measurements Group in Raleigh, North Carolina. The high gain amplifier was necessary to increase the analog voltage signal from the strain gage to a level that LabVIEW could interpret.

Renovating the Tinius Olsen Machine

The UTC mechanics of materials laboratory has two TO machines. The larger load capacity machine was purchased in 1968. At that time, the machine came with an electronic extensometer but was seldom used and eventually was misplaced. Instead, TO mechanical extensometers were used with the TO machine to perform tension tests on nominally 0.5 inch diameter, 2 inch long threaded end specimens made from different materials. Tinius Olsen sells a Model 398 digital indicating system that is a retrofit package designed for use on the system that UTC owns. It costs about $15,000 fully installed. The 398 system replaces the dial indicator and recorder originally installed on top of the Tinius Olsen machine. The 398 system enhances the testing capabilities of the old tester, but does not provide the computerized data acquisition, analysis, and presentation that are available by using LabVIEW. The total costs associated with the retrofit has been about $5,000.

The junior level, core mechanics of materials laboratory at UTC is traditional in that hardness, impact, tension and compression, and torsion experiments are conducted. Recently, we have developed at UTC a bending experiment on a simply supported beam (long rectangular bar) loaded with static weights using data acquisition and LabVIEW. The bending experiment was the first venture of introducing electrical LVDT (linear variable displacement transformer) sensors for measuring beam deflection while using typical SR-4 strain gages for measuring the surface strain.

The next venture into introducing electrical sensors and data acquisition into the mechanics of materials lab came from a masters project performed by a graduate student, Stephen McCormack, under the direction of Dr. Charles V. Knight. The project consisted of selecting a 1000 psig pressure sensor scavenged from another similar TO machine that was inserted into the piston hydraulic system of our TO machine. This system drives the 12-inch diameter piston at the base of the load frame of the tester, which applies the load to the specimen. Along with the pressure sensor, an Epsilon Technology Corporation (Model 3542) electrical extensometer was purchase to provide a voltage signal representing the change in axial elongation in the specimen. The project also consisted of selecting a 5B interface board and appropriate signal conditioning modules from National Instruments to filter and amplify both the pressure sensor and the electrical extensometer voltage outputs to levels acceptable for the data acquisition board in the computer.

A TiOlsen LabVIEW application was developed to generate the modulus of elasticity for common metal specimens being tested under a tension loading. On the front panel of the VI, digital control boxes were provided for input of the specimen diameter and for the gage length. Most of the round threaded end specimens used in the laboratory are nominally 0.5 inches in diameter with a gage length of 2 inches. Also, a digital control box was created to allow input to select the material being tested (steel, aluminum, brass, copper, cast iron, and magnesium). The digital indicator output boxes on the front panel show the fluid pressure being applied from the TO machine, the load being applied to the specimen, the calculated axial normal stress, the change in length (axial deformation) measured by the extensometer, and the calculated axial normal strain. The LabVIEW front panel also presents a figure displaying stress (ordinate) and strain (abscissa) test results. The data points on the plot are displayed at the completion of the test, and a linear regression best line fit is passed through the data with the slope (modulus of elasticity) being displayed in the figure. A typical front panel is shown in Figure 1.

A New HiTech Truss Experiment

The Hi-Tech truss was purchased from Hi-Tech Scientific. The truss members are made of steel. The joints are assumed to be pinned to a common plate as in truss theory; however, the members are really welded to a circular notched hub representing the joint. The truss span is 1 meter, and the diagonal members are 30 degrees apart as shown in Figure 2. All members are rectangular in cross-section with dimensions 20 millimeters by 3 millimeters. Quarter bridge strain gages with a gage factor of 2.05 are attached to 7 members. The truss has a total of 13 members so only half of the truss is instrumented. The strain gage measurement instrumentation normally sold with the truss was not purchased. This instrumentation basically amplified the magnitude of the signal voltage from the strain gages and was connected by a pin cable to an electronic board that contained the Wheatstone bridge balancing resistors. In place of the electronic board and strain gage instrumentation, students in the Fall 1998 and Spring 1999 student design projects for the Engineering 447, Senior ME Laboratory, developed a new system using a LabVIEW virtual instruments program, a CB-50 interface board from National Instruments, and a newly purchased 8-channel strain gage amplifier purchased from the Measurements Group in Raleigh, North Carolina. This device amplified the strain gage values from the microvolt range, due to the applied load in some members being held low to avoid buckling, to millivolt range so LabVIEW could calculate strain, stress, and internal member force. A gain of 2000 was applied to each of the seven channels of strain gage data to achieve the necessary voltage for the LabVIEW virtual instrument (VI). The load is applied to the truss by a proving ring load cell consists of a ring whose deflection is measured by a dial gage indicator at the center of the load cell. The load cell calibration data provided was entered into Excel and a linear regression was performed to determine the best line fit. The results of this are

Force applied (N) = 9.0368* Dial gage reading - 6.1483
Force applied (lb.) = 2.03 * Dial gage reading - 1.38

The load cell can connect to several different points on the truss. One location is the joint in the bottom center of the 1 meter long truss (half-span). Also, the force can be applied at the apex of the roof truss. Another location is at a joint at the quarter span on the long 1 meter span. A fourth location is at a joint along the diagonal members of the truss where the load is applied perpendicular to the member or at a 60-degree angle from the horizontal line through the center of the joint. For further detailed information related to the construction, loading and general use of this apparatus, consult the SM.14 Structures Apparatus Instructional Manual from Hi-Tech Scientific.

On the Hi-Tech Truss.vi front panel, the user inputs in a digital control box the load cell deflection from the load ring dial indicator. The LabVIEW block diagram program calculates the load applied using one of the calibration equations and displays the value in a digital indicator box. Also, the program calculates and displays in digital indicator boxes the microstrain, the normal stress, and the internal forces in each of the seven-instrumented members. The front panel also displays digital control boxes for each member to record the value of the gain added to the bridge (usually at a maximum of 2000). This front panel is shown in Figure 2.

Note that in the study of frame or truss structures, the experimental methods of determining the stresses and strains in the members and the deflections at the joints of the frame tend to be neglected due to the lack of suitable apparatus. The main difficulties experienced are in the methods of loading and directly reading the strains in the members. For example, the adding of dead weights to load a structure is not satisfactory due to the difficulty of lifting and placing the weights without causing vertical oscillations of the whole truss. It is also difficult to simulate a wind load (or horizontal loads) using dead weights. This apparatus allows the experimenter to set up and load the truss in several ways and to measure the strains in the members and compare with theoretical calculations using the methods of joints or sections from statics. Software like TK Solver, Mathcad, or Excel is used to theoretically model the truss. Also, note that the apparatus uses rigid-jointed plane structures to simulate the force distribution in pin-connected structures. Rigid-jointed frames or trusses are able to resist bending moments at the joints, but for determinate structures, only the bending moments generated are caused by changes in length of the truss members. Since the tensile normal strains are usually small in magnitude, the resulting bending moments are small in magnitude. Therefore, the structure behaves approximately as though it were pin-jointed. Further, the strain gages are mounted in pairs, one on each side of the truss members, so the strain components due to any bending are equal and opposite thus, canceling out.

A New Cantilevered Truss Experiment

This experiment again began as a student design project from the Engineering 447, Senior Mechanical Engineering Laboratory. The student group performed the statics using method of joints and sections and entered the equilibrium equations into TK Solver and solved for external reaction forces and internal member forces given an applied load at the end of the truss. Later, they entered normal stress and normal strain equations to the model. The load is being applied by static weights placed onto a hanger that is S-hooked onto the end of the cantilevered truss. Due to the limitations in loading the truss in this manner, the student sized the cross-section area of the truss members. The cross-sectional dimensions are one-fourth inch by one-fourth inch. The members are 10 inches long both horizontally and vertically. The diagonal members are at 45 degrees from the horizontal. The material chosen for this truss is aluminum with a modulus of elasticity of about 10×10^6 psi. All joints are assumed pinned even though the members are attached to an aluminum gusset plate using a multiple number of compression roll pins as fasteners. The truss was fabricated in the UTC Mechanical Shop. Six SR-4 type strain gages were then bonded on the front surface of each member. These quarter bridge strain gages have a gage factor of 2.05. Similarly to the simply-support truss experiment, the gages were wired to a CB-50 board, which was connected to the 8-channel strain gage output amplifier. Again, the maximum possible gain of 2000 was placed on the signal to amplify the microvolt output from the gages. From this point, the amplified signals were sent to the data acquisition board in the computer and interpreted by LabVIEW. The student design group also designed the LabVIEW application called Ctruss.VI. The digital control (input) boxes on the front panel display the load applied in pounds, the gain for each of the six strain gages, and zeroing microstrain required to produce the no-load position. The digital indicator (output) boxes display the microstrain, the normal stress in psi, and the internal tension or compression forces in pounds for each of the six members. The front panel for the LabVIEW application is shown in Figure 3.

Evaluation of these Experiments

At the end of the Fall 1999 semester, an evaluation form for the three new experiments was created and given to one section of the ENGR 247 mechanics of materials laboratory class. The questions and results are shown.

The survey conducted consisted of the following questions. The students were instructed to react to these questions concerning only the new experiments in the laboratory, which I listed for them. Ten of thirteen students in the lab section responded to this survey.

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Evaluation of the Updated Tension Test with LabVIEW, the Hi-Tech Truss Experiment, and the Cantilevered Truss Experiment

Respond by circle the numbers below each question.
Note the 5 – Strongly Agree; 4 - Agree; 3 – Neutral; 2 – Disagree; 1 – Strongly Disagree

1. The updated tension test experiment created a clearer understanding of the concepts of stress and strain diagrams and the determination of the modulus of elasticity

   5 students – Strongly Agree
   4 students – Agree
   1 student - Neutral

2. The Hi-Tech Truss experiment created a clearer understanding of the concepts of truss analysis studied in both statics and in mechanics of materials.

   5 students – Strongly Agree
   3 students – Agree
   2 students - Neutral

3. The cantilevered-truss experiment created a clearer understanding of the concepts of truss analysis studied in both statics and in mechanics of materials.

   3 students – Strongly Agree
   2 students – Agree
   4 students – Neutral
   1 student – Strongly Disagree

4. The experiment handout for the updated tension experiment contains adequate lab objective and lab procedure information to conduct the experiment.

   6 students – Strongly Agree
   4 students - Agree

5. The experiment handout for the updated tension experiment contains adequate information concerning the electronic sensors - pressure sensor and extensometer.

   6 students – Strongly Agree
   3 students – Agree
   1 student - Neutral

6. The experiment handout for the Hi-Tech truss experiment contains adequate lab objective and lab procedure information to conduct the experiment.

   7 students – Strongly Agree
   3 students - Agree

7. The experiment handout for the Hi-Tech truss experiment contains adequate information concerning the usage of the load cell - proving ring and applied strain gages.

   3 students – Strongly Agree
   6 students – Agree
   1 student - Neutral

8. The experiment handout for the cantilever-truss experiment contains adequate lab objective and lab procedure information to conduct the experiment.

   4 students – Strongly Agree
   6 students - Agree

9. The experiment handout for the cantilever-truss experiment contains adequate information concerning the usage of the applied strain gages.

   4 students – Strongly Agree
   6 students - Agree

10. I have learned more from these newer experiments using data acquisition with the computer than the other traditional experiment in the laboratory.

   4 students – Strongly Agree
   3 students – Agree
   3 students - Neutral

Additional Student Comments:

- ♦ I feel it is good to see how the strain gages can be used. I also feel the less involved the student becomes, the less is understood.

- ♦ I gained much experience with using Excel and TK Solver! It has been an overall enjoyable lab.

- ♦ I enjoyed the updated tension test and the Hi-tech truss experiment. Both gave good data that was close to the modeled values.

Conclusions

The renovation of existing laboratory experiments using electronic sensoring devices, data acquisition, and computers using LabVIEW can be cost effective compared to the investment of new laboratory equipment. The renovation of the Tinius Olsen testing machine definitely improved the process of obtaining a value of modulus of elasticity for a given material. The method of reading the TO machine dial indicator to find force applied to the specimen and the use of a mechanical extensometer to measure axial deformation is now an event of the past. Also, the manufacture and instrumentation of the cantilever truss at the UTC mechanical and electrical shops offered cost savings. In purchasing the Hi-Tech truss, the stain gage box indicators sold by HI-Tech were not needed as modern strain gage signal conditioning and data acquisition systems were incorporated in the system. Hi-Tech does not sell any form of computer assisted data acquisition analysis and presentation that was used in the new system.

The use of a industry state-of-the-art data acquisition boards and signal conditioners, modern electronic sensors, and LabVIEW programming in selected engineering laboratories can only strengthen the ability of the student to understand the experimental processes that complement the fundamentals taught in the UTC engineering curriculum.

References

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Charles V. Knight

Charles V. Knight received B.S., M.S., and Ph.D. degrees in mechanical engineering from The University of Tennessee at Knoxville. Dr. Knight has been a member of The University of Tennessee at Chattanooga faculty since 1979, having taught at The University of Tennessee campuses in Nashville and Knoxville ten years previously. His teaching interests are associated with fluid mechanics and thermal sciences. He completed six years of research for Tennessee Valley Authority associated with combustion and exhaust gas emissions and indoor air quality influences for wood burning heaters and boilers. More recently Dr. Knight has been responsible for mechanical engineering curriculum revisions and lab development at UTC. Dr. Knight is a registered Professional Engineer.

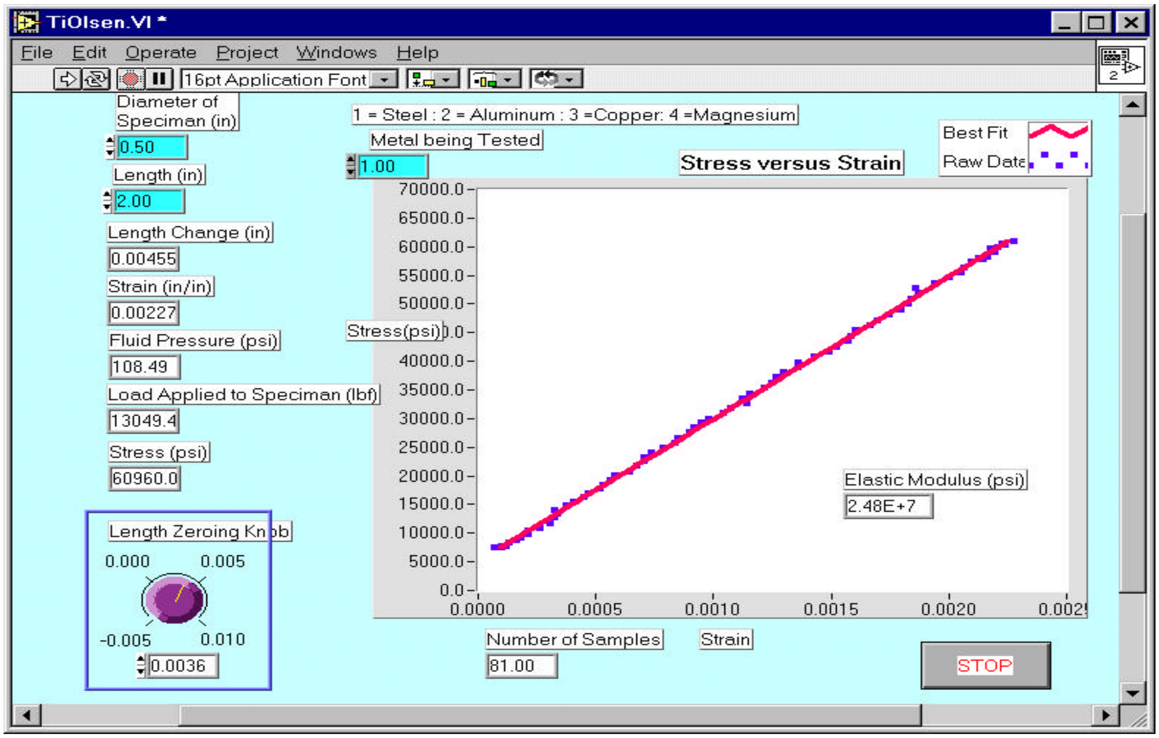

Figure 1: Front Panel of LabVIEW Virtual Instrument

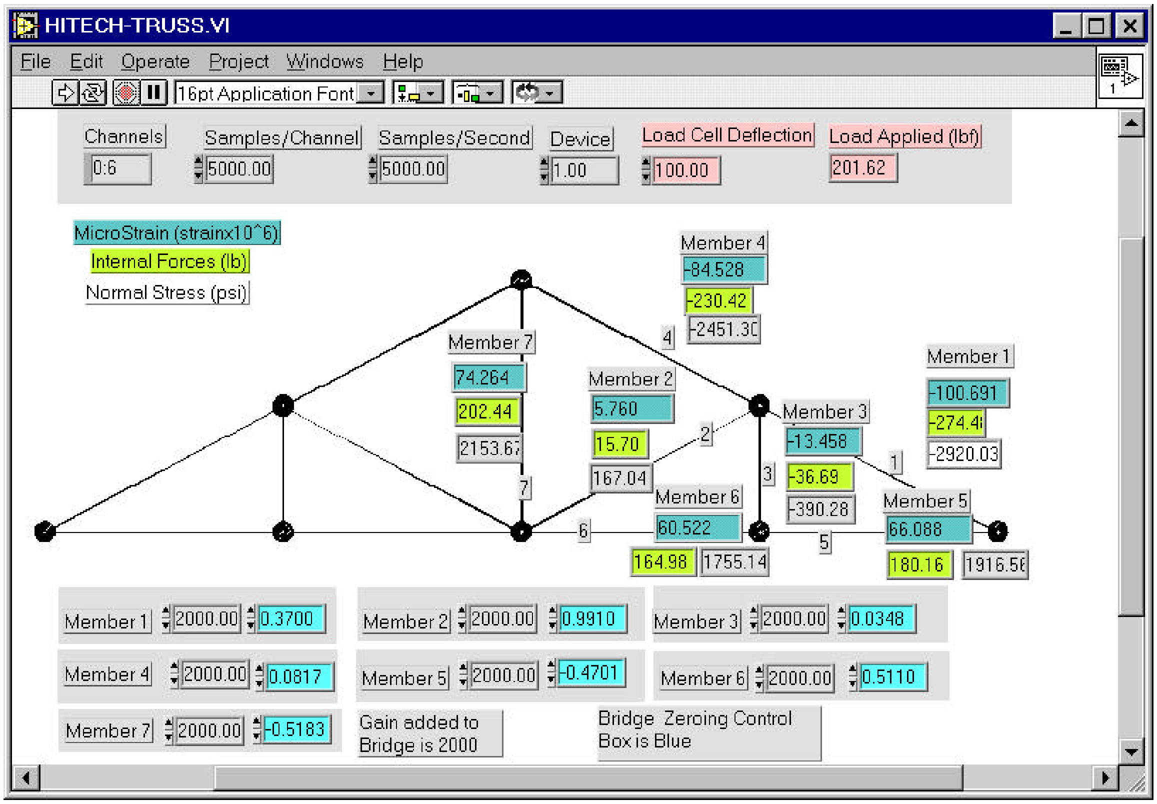

Figure 2: Front Panel for the Hi-Tech truss

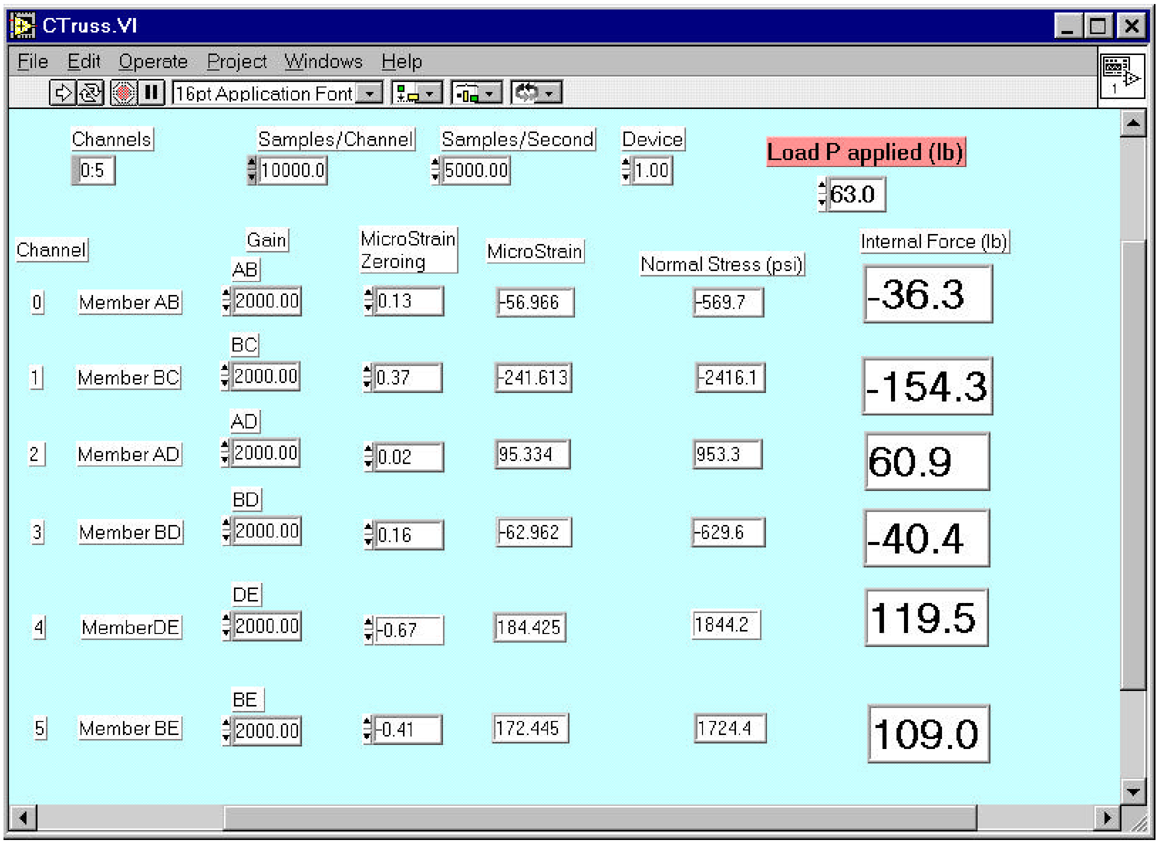

Figure 3: Front Panel for the Cantilevered Truss