2006-2136: A REMOTE LABORATORY FOR STRESS AND DEFORMATION STUDY

Alamgir Choudhury, Western Michigan University
Alamgir A. Choudhury is an assistant professor of industrial and manufacturing engineering at Western Michigan University, Kalamazoo, Michigan. He earned his MS and PhD from NMSU (Las Cruces) and BS in mechanical engineering from BUET (Dhaka). His interest includes computer applications in curriculum, MCAE, mechanics, fluid power and instrumentation & process control. He is also a Registered Professional Engineer in the State of Ohio and affiliated with ASME, ASEE, SME and TAP.

Jorge Rodriguez, Western Michigan University
Jorge Rodriguez is an Associate Professor in the Department of Industrial and Manufacturing Engineering and a Research Associate of the Human Performance Institute at Western Michigan University. He received his Ph.D. in Mechanical Engineering from University of Wisconsin-Madison and his M.B.A. from Rutgers University in Piscataway, NJ. Dr. Rodriguez teaches courses in Computer-Aided Design and Manufacturing, Mechanical Design, Biomechanics and Finite Element Analysis. His research is in the field of computers in engineering, particularly in machine design, systems modeling, and biomechanics.

Sam Ramrattan, Western Michigan University
Sam Ramrattan is a professor of IME department at Western Michigan University. He has BS in manufacturing engineering, MS in management technology and PhD in industrial technology. His areas of research and publications are metal casting, plastic process, materials and manufacturing process improvement. He is a professionally active member of ETP, TAP, SME, SPE, AFS and Key Professor of Foundry Education Foundation.

Mitchel Keil, Western Michigan University
Dr. Keil is an associate professor in the Industrial and Manufacturing Department at Western Michigan University. He received his Ph.D. from Virginia Polytechnic Institute (VPI&SU), his MS from Florida Atlantic University, and his BSME from VPI&SU. His areas of expertise are mechanisms, computer graphics, CAD/CAM/CAE, and vibrations. He is a registered professional engineer in the State of Florida. He has had industrial work experience at Litton Poly-Scientific, Motorola, and Bethlehem Steel Corp.

Pavel Ikonomov, Western Michigan University
Dr. Ikonomov is an assistant professor in the Department of Industrial and Manufacturing Engineering at Western Michigan University. He received his Ph.D. in Mechanical Engineering from Hokkaido University, Japan; his M. Eng. from Muroran Institute of Technology, Muroran, Japan and M. Sc. from Technical University of Varna, Bulgaria. His research is in the field of Virtual Reality simulation, Nanotechnology, CAM, Tolerance modeling and inspection.

Abhishek Goyal, Western Michigan University
Abhishek Goyal graduated with a Masters in Manufacturing Engineering from the Department of Industrial and Manufacturing Engineering at Western Michigan University in December 2005. He has a BS in mechanical engineering from Bangalore Institute of Technology. As a graduate student he worked in several sponsored research projects in design optimization and online control system. He is proficient in AutoCAD, Unigraphics, SolidWorks, Pro-E, Promodel and Maxwell 2D system and has programmed in C, C++ and html environment.
A remote laboratory for stress and deformation study

Abstract

Analysis of stress and deformation in beam elements are utilized in a wide range of curricula in both engineering and engineering technology programs. In a typical undergraduate class, learning of a theoretical method is often reinforced by computer aided analysis and practical experiments in a formal laboratory setting. Using the current technology, in a lecture only mechanics class, certain theoretical learning can be complemented by online experimental verifications without leaving the lecture class. The paper addresses development of a laboratory setup that can apply load to a beam element and allows monitoring the resulting stress and deformation through the web. The laboratory consists of a pneumatic beam loading mechanism, stress and position sensors, data acquisition system, and application programs for data monitoring, analysis and control. Using this system, one can quickly create an experimental setup for a theoretical problem, apply the load, and record the resulting stress and deformation remotely through the web. Close agreement between the analytical and experimental results would establish the validity of the theoretical solution without the use of a formal laboratory class. It would also create awareness among the students of the class on limitations of the theoretical methods to predict the behavior of structural members in reality. The use of modern sensors, data acquisition instrumentation and application programs to monitor and control such an application can also be beneficial as laboratory practices for undergraduate level hydraulics/pneumatics or instrumentation classes.

Introduction

Stress and deformation analysis\textsuperscript{1,2} is an integral part of undergraduate level mechanical design curricula in both engineering and engineering technology programs. The goal is to teach stress and deformation analysis for design of mechanical components and system. It includes setup of a problem for stress and deformation analysis based on applied external loads, select the most effective method to solve the problem and apply the result to design a safe and functional component. The effectiveness of this learning depends on the depth of subject matter covered and the method of instruction. In the engineering technology programs, the emphasis is on mastering the techniques and tools for the solution of a problem. After learning the theoretical foundations, students use both analytical and computer assisted solution methods for this purpose. They are also introduced to
commercial tools or customized software packages for solution of a specific design problem. An important part of their learning is to learn how to develop a problem based on the given criteria, use an efficient solution method or select an appropriate solution tool. In the laboratory classes students verify their theoretical solutions by measuring the actual stress and deformation in the experimental system. To overcome this learning deficiency in a lecture-only class, we are presenting a method to verify the theoretical stress and deformation in a remote beam element through the web without leaving the class room.

The technology involved with remote laboratory experimentation has been utilized in various fields. It is also used for remote monitoring and control of a variety of engineering systems and processes. Esche, et. al. introduced an internet accessible laboratory for cost effectiveness and flexibility in an undergraduate dynamics class. Francisco, et.al. utilized online robotic experiments to allow a large number of students to benefit from a physical laboratory in distance education courses. As it required no specific timetable for the laboratory, students could use this system to learn at their own schedule. Similarly, Rohrig used an internet accessible laboratory for enhancing distance education in control engineering. Besides analytical computation, these systems require use of high level programming language to monitor, process and transmit various application data. In the area of automated measurement of quantitative data in engineering applications, LabVIEW is a popular programming language. Krehbiel used a LabVIEW tool to remotely access controllable laboratory equipment for online experiments in environmental and ecological science. His objective was to focus on pedagogical issues related to learning through a remote system rather than real time experimentation.

In the following, a new tool is presented for online experimental verification of theoretical results in a mechanics class. The goal is to create learning opportunities for students beyond traditional lecture and problem solving. This is done by using two different methods: computer aided analytical solution, and verification of these results by actual experimentation in a remote laboratory. The computer aided solution method was developed earlier and the online experimentation is augmented to that. The method utilizes a pneumatic actuation system that can be remotely accessed and controlled through the web. The system allows one to load a simple beam element in the laboratory as specified in a theoretical problem, measure the resulting stress and deformation, and compare with the analytical solution.

**Computer aided analysis tool**

Recently, a web based application package has been developed to provide students with a structured guide to lead through the steps of problem formulation and solution method taught in the class. The computer-aided analysis tool is available to the students for the solution of stress and deformation in a simply supported, over hanging or cantilever beam elements. To use this tool one starts with the selection of type of analysis - stress or deformation. In Figure 1 below, the steps followed in the stress and deformation analysis
are shown. The user specifies the type of beam, and the nature and number of the loads. As the user enters magnitude and location of each load, the corresponding reaction forces, shear force, and bending moment distributions are displayed. After the last load is specified, the user can select a critical section of the beam to compute bending and shear stresses, determine the state of stress, and investigate stress transformation and the principal stresses. In this module, students can independently analyze a subset of a problem or perform complete stress and deformation analysis of a problem. Similarly in the deformation analysis module, one selects the type of beam and specifies the loading parameters to produce the deflection chart and deflection curve.

Figure 1
Computer aided stress and deformation analysis
Online experimentation tool

Due to lack of hands-on experimentation, in a lecture class, students do not see the effectiveness of the theory learned in real-life applications. Students also tend to overlook the limitations of the theoretical methods and cause of variation between the theoretical and actual behavior of mechanical bodies. Therefore, this tool was developed to show the actual behavior of a beam element within the limitations of a lecture class. It allows the students to setup a beam problem in a remote laboratory that they have already analyzed theoretically. Using the online input, students specify magnitude and location of the loads, actuate the system to apply the loads on a real beam element and see the resulting stress and deformation. A configuration of the overall experimentation tool is shown in Figure 2.

![Figure 2](image)

Configuration of online experimentation system

Laboratory setup

The system was developed in the Parker Motion Control Laboratory of Western Michigan University. Initially existing hydraulic equipment in the laboratory were used for feasibility study of an online actuation and open loop control of the hydraulic actuators. To apply a load remotely through the web, it is necessary to keep the complete system running at all times. Considering the noise level, and wear and tear of equipment, a pneumatic system was an eventual choice for the project (Figure 3).
A portable pneumatic system was designed to apply a load of up to 100 lb on a 2 feet long steel beam specimen. Components not available in current laboratory were purchased locally and assembled. It is composed of an aluminum beam-loading platform along with a simply supported beam element installed in the lower level of the system. A constant-pressure load-holding pneumatic circuit is utilized to control the location and magnitude of the load in the upper level. It includes a horizontal pneumatic cylinder with a 2 feet stroke moving the loading cylinder mount above the beam element. This cylinder utilizes a 0-10 volt input signal and a flow control valve to determine the location of the load by providing a series of pressure pulses on each end of the piston. The loading cylinder with 2 inch stroke is attached to this sliding cylinder mount. Magnitude of the applied load is controlled by input pressure to this cylinder through a pressure control valve.

The system is monitored by a National Instrument (NI) data acquisition system in the laboratory which includes a PXI 1000 data acquisition chassis, embedded PXI & VXI controllers, PXI multifunction input/output kit, shielded connector blocks, and terminal blocks. Using a LabVIEW application program, real time stress and deformation data are acquired in a database in the PXI server. A Visual Basic (VB) application program utilizes the same loading parameters to compute stress and deformation analytically. The user of the system specifies the locations of the load and its magnitude through inputs in this VB application program. Strain gages are installed in 5 locations at the bottom face of the beam and used as target points for an analysis problem. These gages send signals to the LabVIEW application program through the strain gage module in the PXI system. Besides simply supported beam, the system can also be configured to measure stress and deformation in over hanging or cantilever beams as well.

**Implementation method**

Appropriate data base architecture and web applications have been developed to integrate the use of a computer-aided analysis and online experimentation tool. After the initial login process, the user may choose the stress and deformation analysis or online experimentation. For the experimentation module, a second web security system is developed to prevent unauthorized break in from the internet and to limit access to the physical laboratory equipment to only one authorized user at a time. After gaining this access, the user goes through a step-by-step procedure for the initial system check and specifies the magnitudes and locations of the load. Based on the user input, signals are transmitted to the actuators of pressure and flow control valves through the NI data socket server reader and writer. Once the loads are applied, on board strain gages and deflection transducers send stress and deflection signals to the PXI data acquisition system. Using a LabVIEW application program, this data is displayed in both tabular and visual form and posted in the web through the LabVIEW web publishing tools. This experimental result is compared with the analytical result obtained earlier to verify the effectiveness of the theoretical analysis.
Combined use of the analytical and experimental tools for specification of a problem, system setup and comparison of the results are shown in Figure 4.
Initially, the system will be used to demonstrate solutions of example problems already addressed in the lecture class. Later the system will be available to students enrolled in the class to solve other problems outside the class at their own schedule.

Conclusions

Visual Basic and LabVIEW programming allows students to use the computer aided analysis tool and the online experimentation to address the same problem. VB based stress and deformation analysis tool leads students through a step-by-step learning process taught in the class. Combined use of the computer-aided solution and the laboratory experimentation will maximize the students’ learning of the subject taught in a lecture class. The web based tool may also be used for distance education and laboratory practices in fluid power and instrumentation classes.

References


