University of Colorado at Boulder Instructional Centrifuge

Introduction

CU's instructional centrifuge is a state of the art tool for teaching geotechnical principles to undergraduate engineering students. Centrifuges have been used as tools in geotechnical research for over fifty years. They provide a convenient method for testing reduced scaled models of engineering structures under the stresses and loading conditions that realistically duplicate prototype behavior. The importance of geotechnical centrifuges is often compared to the role of wind tunnels in aeronautic research. In the last decade an instructional centrifuge has been used in undergraduate education at the University of Colorado. Through hands-on exercises, students observe the failure mechanisms of slopes, retaining walls and foundations in addition to being introduced to the principles of experimental research. The centrifuge is equipped with in-flight digital image processing and load measurement capabilities, making quantitative evaluations of test results convenient. As various didactic units are developed, the test description and results will be posted. Please feel free to use them in your instructions. If you have some test ideas that you would like to have developed, please contact us and we will be glad to cooperate with you in developing the test and sharing the results on this site. This project was supported by the Division of Undergraduate Education Program of the National Science Foundation under the Cooperative agreement No. DUE-0341327 and by the Warkley fund of the Department of Civil, Environmental and Architectural Engineering, University of Colorado at Boulder.

Analog Data Acquisition System

The instructional centrifuge utilizes an inexpensive National Instruments PCI-6014 multifunction data acquisition card. This card provides eight differential input channels and two analog output channels. The resolution is 16 bits. This card is used primarily for reading the analog output generated by the onboard load cell. Excitation power, provided by an external 10 Volt DC power
supply, and signal return circuits are routed to and from the rotating centrifuge arm by a 12 channel electrical slip ring assembly. LabVIEW software is used to retrieve, process, and display the values measured by the data acquisition card.

**Drive System**

The instructional centrifuge is powered by an AC digital-brushless servo system. The drive motor is located beneath the centrifuge chamber in the steel support tube. An in-line planetary gear-reducer couples the Kollmorgen AKM-53K motor to the centrifuge shaft through a 3:1 reduction. The gear reduction allows the power output of the motor to be optimized over the speed range required by the centrifuge. The motor is controlled in a closed-loop speed control scheme by a Pacific Scientific PC-834 brushless servo drive. The typical use of this type of servo system is for precise positioning applications. However, due to it's high-performance, ease of programmability, and high level of integration, the servo drive system has proven to be a perfect match for the instructional centrifuge.

Using a digital drive system to power the instructional centrifuge has a number of benefits. The PC-834 drive allows direct control of both speed and torque of the drive train. This precise control allows centrifuge test specimens to be accelerated smoothly to any g level. Once the centrifuge has achieved the required speed, the drive a capable of regulating the g level with an accuracy of +/-0.05 g. Because the centrifuge has a substantial rotating mass, a large amount of energy must be dissipated in order to bring it to a stop. The drive handles this automatically by switching in a dynamic braking resistor that dissipates excess electrical power generated by the motor. With dynamic braking the centrifuge can be stopped from full speed in under 20 seconds. The drive electronics are housed in a fan-cooled wall mounted enclosure adjacent to the centrifuge. Because the drive is a highly integrated unit, the only external connections are a serial cable linking it to the control computer, an emergency disable switch, two cables connected to the motor, and the 208 Volt AC 3-Phase input power connection. The drive system also features a key lock switch to prevent unauthorized use.
Software
All control and data acquisition programs for the instructional centrifuge are developed exclusively using National Instruments LabVIEW. The use of LabVIEW's graphical programming language allows flexible, intuitive applications to be created in a short period of time. Add-in libraries, such as the machine vision module, make LabVIEW a powerful tool for data acquisition and processing, control, and data presentation applications. During a typical test, all of the required LabVIEW Virtual Instruments (VIs) are run on one computer adjacent to the centrifuge machine. Separate VIs are used to control the machine, acquire video data, and acquire analog force measurements. The use of a couple small VIs as opposed to one large VI allows the user to only run task specific programs for a given test.

Centrifuge Control VI
The centrifuge control VI provides the main interface to the drive system. The user sets the desired g level, desired ramping rate, and then switches the drive on. Control is completely automatic. Readouts for actual g, drive motor rpm, drive load (current), and drive system temperature are presented to the user in real time. The implementation of the control program is relatively simple, as the actual motor drive contains all of the intelligence for controlling the motor. The control VI serves mainly to communicate user input and operating parameters to and from the drive over a serial interface.

Image Grabber
The image grabber VI serves a central role in the instructional centrifuge concept. This VI communicates with the image acquisition hardware and receives digital still images from the camera. It also communicates with the other VI's to obtain current g level and force measurements. Depending on the experiment needs, the image grabber can be set up to display the live images, and perform different real time image processing operations. Currently the program can merge the g level value, force measurement, and machine vision derived displacement into the image. This makes each still image recorded to hard drive extremely data rich. Displacement measurements can be made at virtually any point(s) in the test specimen using edge and blob detector functions in LabVIEW. The output of these functions typically give sub-pixel resolution which is converted into engineering units based on calibration of the optical
system. Force vs. displacement is plotted in real time by the image grabber VI, and a file containing numerical data is generated in addition to image data files.

**Force Measurement VI**
The force measurement VI simply acquires force measurements from the on-board load cell via the analog data acquisition system, and makes these measurements available to the image grabber VI.

**Post-processing VIs**
Various post-processing VIs are currently being developed to further extract data from the digital still images. These include programs to analyze slope failures using interactive measurement tools and programs to generate .avi movies from the still images. We are also developing VIs using Maximum Cross-Correlation (MCC) and Particle Image Velocemetry (PIV) techniques. These methods are used to track particle movements through a series of images, and can be used to generate vector fields illustrating geotechnical principles directly from a set of images. These programs are computationally intensive by nature and therefore need to be applied to the image data after a test is completed.

**Digital Imaging**
**Camera**
The instructional centrifuge video data acquisition system consists of a high-resolution analog camera, video capture hardware, and image processing software. A JAI CV-M1 camera is currently in use, and generates 1300x1030 pixel images at a rate of 12 images per second. The electrical slipring assembly routes the camera's video signal to a National Instruments PCI-1409 monochrome video acquisition card. LabVIEW software retrieves the digitized images from the card, processes, and saves the images on the hard drive.

**Optics**
A 12mm fixed-focal length lens was chosen for the camera to provide an adequate field of view with minimal distortion. This lens complements the CV-M1's large format 2/3" image sensor well. Increasing the size of the image sensor to 2/3", versus the typical 1/4"-1/3", allows proportional increase in the field of view without introducing additional "fish-eye" type distortion. Given the tight space restrictions of the instructional centrifuge, and the desire for low-distortion images, the additional expense for a large format camera is well warranted.
Lighting
Solid state Light Emitting Diodes (LEDs) illuminate the test specimen. The LEDs are fixed to the camera mounting bracket and spin with the centrifuge, providing the consistent lighting required for image processing. Light intensity is adjusted externally by controlling current through the LEDs. Because LEDs do not have a filament, they are immune to the high-g environment and have typical life time of over 10 years.

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