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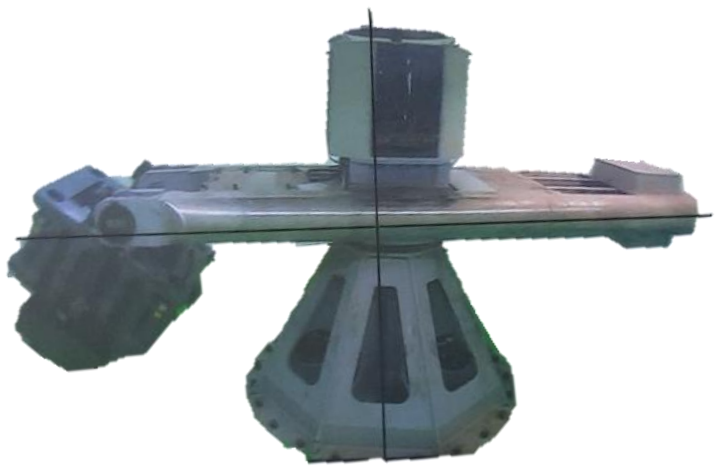
DYNAMIC TESTING SYSTEMS, TRANSDUCERS & SOFTWARE

MULTI-AXIS GEOCENTRIFUGE EARTHQUAKE SHAKE TABLES

Geo-centrifuges are used to perform tests on scaled models of structures embedded in non-linear materials such as soils and rock. For example, if a 100:1 scale model is used, the soil properties will not scale correctly unless the static vertical acceleration is increased from 1 g to 100 g. Similarly, time and acceleration must be scaled up by a factor of 100. Consequently, a 30 second earthquake of 0.5 g acceleration effecting a full-scale structure would have to be scaled in the geo-centrifuge to a 0.3 second earthquake with 50 g peak acceleration. Displacements would be divided by 100 but velocities would be unaffected. Under such scaling, called velocity scaling, the nonlinear response of the soil would be properly simulated.

Geo-technical centrifuges are used extensively for physical modeling. Hundreds of such centrifuges are installed world-wide with payloads from 10 kg to 10 tons. Scaling factors between 50 and 500 are typically used. Test volumes are typically between 0.05 to 3.0 cubic meters.



4m Beam Geocentrifuge Installed in China

There are two general types of geo-centrifuges. Beam centrifuges rotate a long beam about a vertical axis. At one end of the rotating beam there is a swing basket with the test object inside. At the other end there is a counter-weight. The larger units have beam radiuses of 4 to 5 m and maximum rotation rates on the order of 4 Hz. Maximum accelerations are typically 200 g. The other type of geo-centrifuge consists of a vertical drum rotating about its vertical axis. The test items are placed on the inside surface of this drum. Maximum drum diameters are approximately 2 m and can achieve as much as 500 g acceleration.

ANCO has fabricated several small educational beam centrifuges with payload capacities up to 5 g ton. ANCO has also placed multi-axis shake tables inside of larger beam centrifuges with capacities up to 500 g ton. These ANCO shake tables are capable of independent bi-axial vibration in the test sample horizontal and vertical directions. They can achieve up to 40 g acceleration and +/- 5 mm displacement at frequencies up to 300 Hz. Payloads can be up to 700 kg. These are servo-hydraulic driven with an off-arm hydraulic pump connected via a hydraulic slip ring. Multi-channel data acquisition and video monitoring are achieved with an on-arm PXI controller communicating via an optical slip ring. ANCO has also designed a uni-axial circumferential shake table for use in a barrel centrifuge. The design of these shake tables to operate at high

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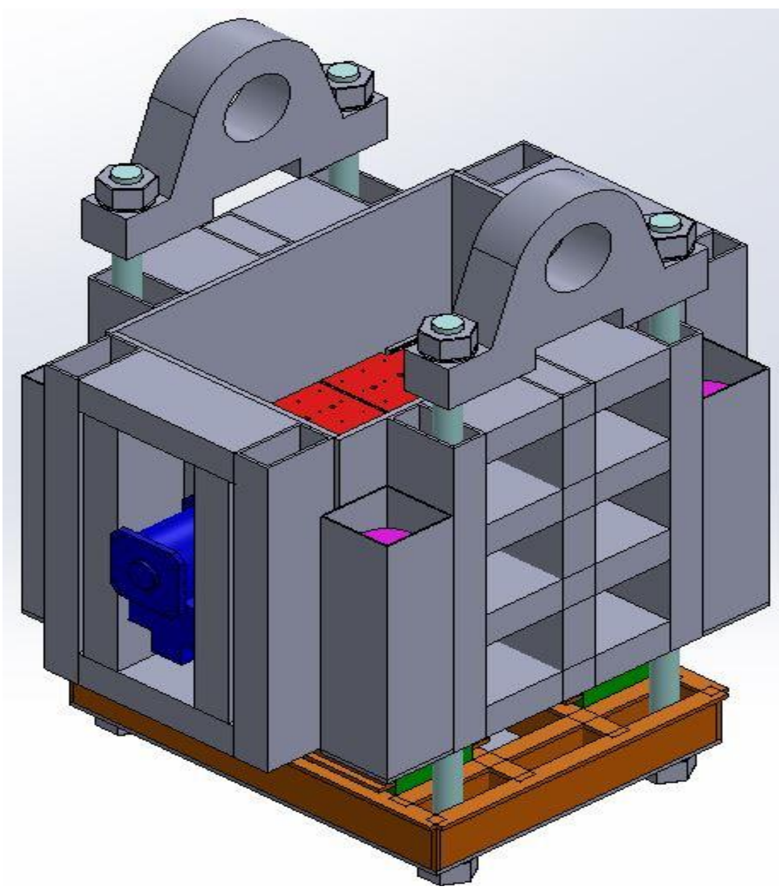
frequencies, multiple axes, and at high static and dynamic acceleration while minimizing weight is challenging and requires creative design solutions. Some of these solutions include the use of laminated rubber bearings for guidance, hydraulic or pneumatic high capacity dead weight support systems and extremely stiff and light weight containment baskets. Servo hydraulic circuit design and line routing is also challenging in centrifuge applications.

Using the shake tables in these geo-centrifuges, researchers are able to investigate non-linear soil foundation issues involved with earthquake and wave action response of dams, pilings, harbor structures, and off shore oil platforms as well as submerged structures affected by water wave action.

The figure below presents an 3D model of an ANCO fabricated swing basket with bi axial earthquake shake table used in the 4 m beam centrifuge shown in the previous photo.

Data Acquisition Challenges in Geo-Centrifuges

Working with geo-centrifuges operating at ~100-200 g static acceleration presents a host of complex and unique technical challenges. Those of mechanical and hydraulic nature have been discussed in the previous article. Other challenges pertain to using data acquisition systems including onboard computers, analogue cards, attached sensors, cabling, video cameras, and optimizing data transmission. Monitoring heavily time compressed seismic tests translate directly to requiring higher data acquisition rates. Along with that requirement data transmission rates increase when communicating with a remote-control PC by several orders of magnitudes and quickly exceed what is technically possible to date. For that reason, on board compact DAQ systems such as a National Instruments PXI's, are required to help manage the analogue signals of sensors, data storage, video streams, and data communication. To minimize high g acceleration exposure to PXI and associated systems it is necessary that all electronics are placed as close as possible to the center rotating axis of a centrifuge where space is at a premium. For example, a 20 lb. PXI system subjected to a static 30 g vector will experience a 600 lb. force. That requires special mounting techniques for every electronic component, connector, power supply unit, USB hub, cable, and sensor. Particular attention is required to the orientation of the electronics and the placement and fastening of connectors. Given the large amounts of data generated and the technical difficulty in streaming such quantity in real time through fiber optical slip rings, that storage must be located on or in the rotating centrifuge. For that, a spinning hard drive is an unwise choice!



ANCO Swing Basket With 2 DOF Shake Table

Using the example of a PXI exposed to a 600 lb. force helps to understand the necessity of securing every electronic component. That also puts in perspective the challenges faced when securing electronic components. For example:

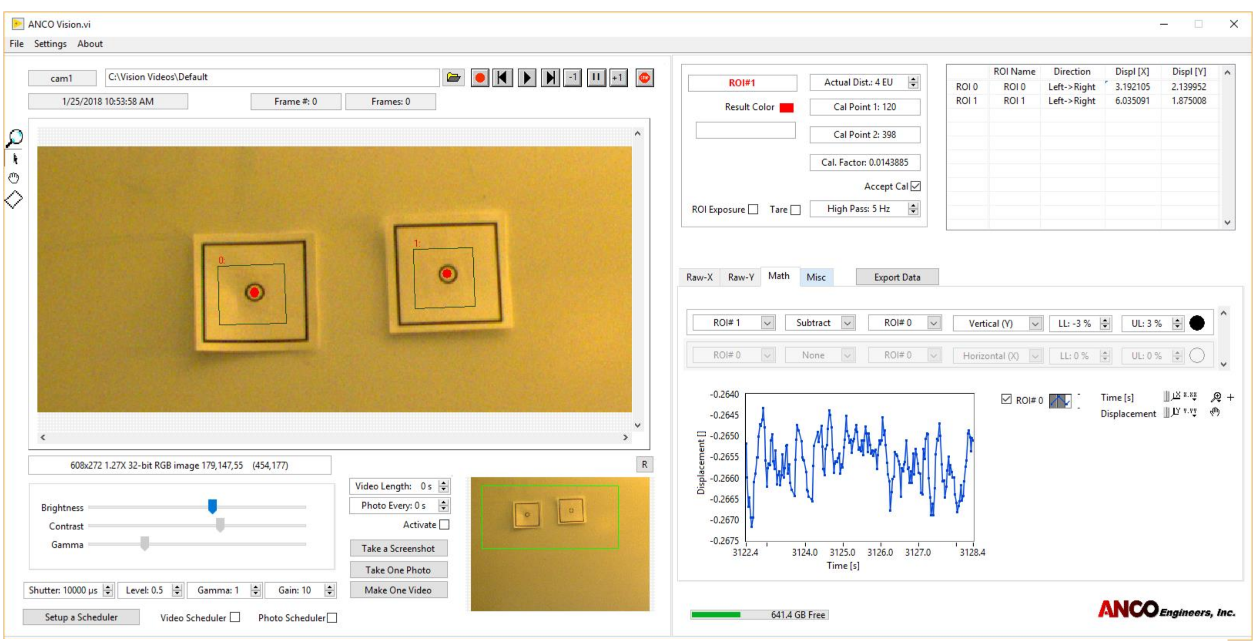
- Placing insulators, mechanical buffers and stabilizing brackets between electronic cards that can short out when touching each other when deflected under high g loads.
- Fastening BIOS batteries.
- Securing onboard press fit electronic chips if surface mounted components are not available.
- DAQ card orientation with sufficiently robust connectors.
- Mechanically stabilizing vertically standing electronic components such as large capacitors, spools, and resistors.
- Building custom steel cable runs to connect to sensors.

Using video systems under 100 g conditions present a particular set of challenges:

- Higher video capture rates (300-500 fps) require additional data monitoring boards.
- Fastening of mechanical camera lens elements such as the aperture and focusing ring.
- Providing additional power for LED illumination.
- Fast loss-less data transmission to PXI systems or equivalent onboard PC's over great distances (6-10 meters).
- Managing high transmission rates when using multiple cameras.
- Camera size, weight, connector type.

Hardware Challenges

To date there are many compact light weight fast video cameras available with sizes smaller than 30 x 30 x 60 mm. A vast majority can be run with standard interfaces such as GigE, Camera Link, etc. All of those are good solutions but require additional electronic hardware thus increasing weight on a PXI chassis for example. With the advent of the high speed USB3.0 interface camera suppliers now provide inexpensive cameras with frame rates in excess of 300-500 fps. Many of these devices can be solely powered by the USB 3.0 interface which makes this an attractive solution because transmission rates are similar to that of GigE. Additional benefits are lockable USB cables which work very well in static high g environments. Disadvantages are that such USB cameras are very power hungry and quickly exceed any PC's on-board USB power capacity. Therefore, it is necessary to use multiple self-powered USB hubs to feed multiple cameras.



ANCO Vision Motion Tracking Software

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Typically, USB cables can transmit data reliably over an about 2 meters length. That poses a significant challenge in large centrifuge applications when several meters long cable runs are required. It is therefore necessary to replace USB3.0 cables with optical fibers en/decoder systems with integrated power lines.

Software Challenges

Using a functional camera/electronic package described above provides a reliable data solution for fast transmission rates. Often several cameras are attached to a centrifugal seismic payload and each camera cuts into the total available data transmission limit. Making the most of that available digital real-estate is the goal when providing software that is used to record and manage collected video images. There are multiple solutions to such an approach and some of them are functional but are not useful:

- Size of the video. The larger the size the greater the data transmission requirements.
- The video format such as RGB-8bit, RGB-16bit, Gray Scale-8bit, YUY1, MPG, etc.

These features impact the transmission speed as the square of the pixel resolution!

Upon the selection of the appropriate video mode and depending on the camera manufacturer, it is possible to further enhance transmission speed by specifically programming the camera's internal functions and attributes. Using these features push most of the computational video pre-processing to the cameras firmware greatly reducing software related overhead.

The top real time speed savers are:

1. Brightness, Contrast, Gamma Values.
2. Gaussian Sharpness Algorithm.
3. White balance.
4. Backlight compensation.
5. Dark current optimization.
6. Automatic noise reduction.
7. Flicker reduction when using LED and Neon Lights.
8. Morier pattern and fringe elimination.
9. Fixed shutter speed and aperture settings.
10. Active region of interests (ROI's).
11. Edge tracking.

Using fiber optical slip rings to transmit data to a remote-control PC is a good solution. Optical slip rings however are not immune from dropping data packets. That forces most data storage to an on board solid state hard drive. In addition, running software for image processing on PC targets inside a centrifugal environment reduces further transmission requirements. This method of optimizing data transmission and processing allows the remote monitoring of an onboard PC using a remote desktop utility which in comparison is very low on data usage and easily handled using slip rings.

Vision PXI and Camera Hardware

Conclusion

A clear understanding of the environmental conditions in a geo centrifuge with respect to mechanics, electronics, and digital data transmission restrictions is required to derive reliable hardware and software solutions to acquire data efficiently.

The previous images show ANCO's vision software and hardware. This system acquires data at 300-500 fps using USB cameras at 100 g static force. Its purpose is to monitor and measure displacements and vibrational modal shapes on models subjected to simulated time compressed seismic events. Displacement accuracies are on the order of tens of microns. This system monitors multiple regions of interests (ROI's) simultaneously per camera with a total of six cameras operating in parallel.

In addition to using on camera processing software, the PXI uses a LABVIEW VI for executive management and communication.

For more information, contact Dr. Paul Ibanez or Dr. Michael Schulze