The Modernized U of C Seismic Physical Modelling Facility

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Summary

The University of Calgary Seismic Physical Modelling Facility has been in existence since 1985. Recently, we overhauled the system, replacing obsolete components with modern and improved alternatives. The guiding principle we followed in making changes was that the revamped facility be capable of accurately and efficiently simulating high-resolution 2D and 3D seismic surveys in both land and marine environments. To this end, we have constructed an automated facility that incorporates a six-axis positioning system using linear electric motors, arrays of transmitting and receiving transducers, fast analogue-to-digital acquisition, and customized control and acquisition software. We present examples of data gathered from a model 2D marine seismic survey.

Introduction

Scaled-down physical modelling of seismic surveys has been done by the Department of Geoscience at the University of Calgary for many years (Cheadle et al., 1985). The original facility used stepper motors and chain-and-sprocket mechanisms for moving and locating transducers. Positioning repeatability was poor because of excessive backlash in the mechanisms. The original software for motion control and data acquisition was written in the QuickBasic language and executed on a desktop computer running under MS-DOS. By the early 2000s, the programming language and the operating system were obsolete and unsupported. Thus, both the hardware and the software components of the original modelling facility needed significant changes and upgrades. It was decided in 2005 to completely rebuild the facility.

The Positioning System

The new positioning system employs modern linear electric motors with sophisticated motion controllers from Parker Motion Corporation. Eight linear motors with position encoders and motor drives are configured in a two-gantry orthogonal motion system. Each gantry has 4 motors. Two of these motors work together to move the gantry in the X direction. The two remaining motors are mounted on the gantry so as to move an equipment carriage in the Y and Z directions. The eight motors on the two gantries are controlled by computer commands issued to a controller board installed in a desktop PC running the Windows XP operating system. Transmitting and receiving transducers that generate and detect ultrasonic seismic pulses can be mounted interchangeably on the two gantry carriages and be moved precisely and independently in three orthogonal directions. Positioning is accurate and repeatable to within 0.1 mm.

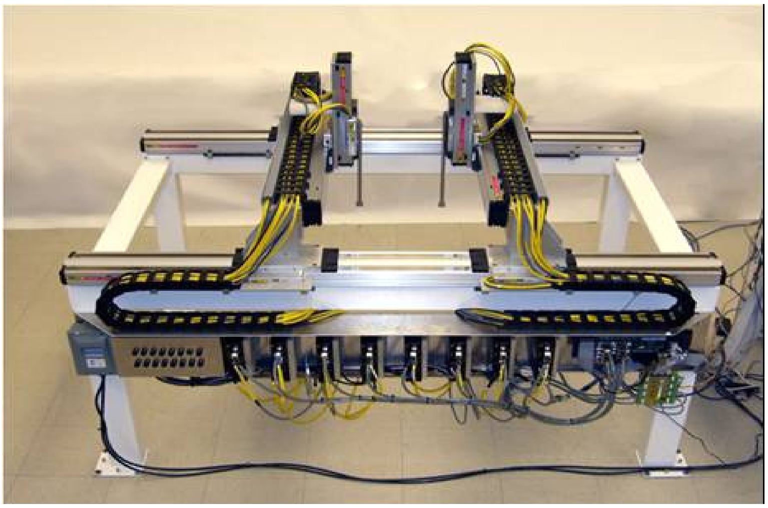

Figure 1: The six-axis 3D positioning system (-/+ X is left/right, -/+ Y is towards/away, -/+ Z is up/down). Gantry A is to the left; Gantry B is to the right.

Figure 1 shows the two gantries, AC power switches and fuses, eight motor drives, and motor controller mounted on a steel frame. The frame has dimensions of 1800 mm long by 1200 mm wide by 900 mm high, and scaled-down physical models with dimensions smaller than these can be placed within the frame beneath the gantries. After installation on the frame, the maximum ranges of motion for the X, Y, and Z motors are 1100 mm, 800 mm, and 160 mm, respectively. The standard model scale factor is $1:10^4$, so these dimensions represent a real-world volume of 10.0 km by 8.0 km by 1.6 km.

Piezoelectric Transducer Arrays

For generating and detecting ultrasonic seismic waves, we use piezoelectric transducers called piezopins. A piezopin consists of a very small cylindrical piezoelectric element (approximately 1 mm diameter by 0.5 mm long) bonded to the tips of thin metal tubes (about 1.6 mm diameter by 150 mm or 19 mm long). These are wired to RG174/U coaxial cables terminated by standard BNC connectors. In water, the piezopins have natural dominant frequencies of about 1.0 MHz. Assuming a model scale factor of 10^4, the 1 mm diameters of the piezopins mimic real-world source/receiver footprints of 10 m, and the dominant frequencies scale down to real-world values near 100 Hz.

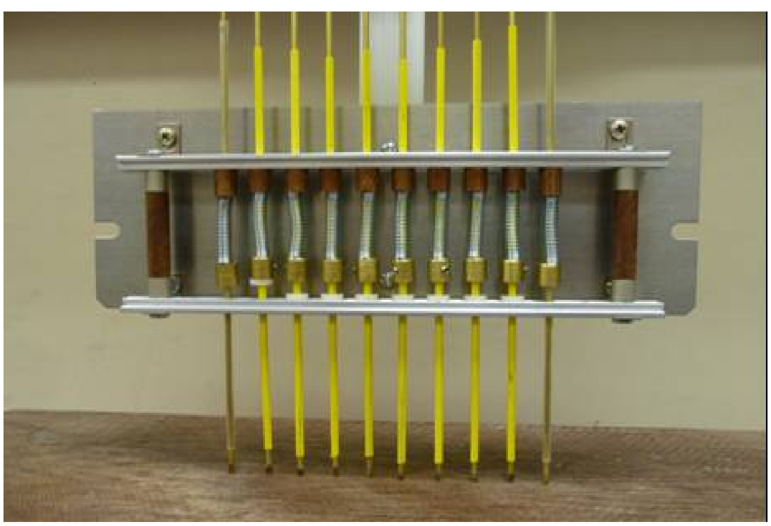

Figure 2: A linear array of ten piezopin transducers. Adjacent transducers are separated by 10 mm. In this array, the two end transducers are used as receivers; the eight transducers in the middle are used as transmitters.

Because of their small size, the piezopins are well-suited for constructing arrays of multiple transducers. In any modelling experiment, moving transducers to their desired positions is the most time-consuming operation. By employing multichannel receiver and transmitter arrays, we can decrease the number of transducer moves significantly, and so increase the efficiency of experiments that simulate high-resolution 2D and 3D surveys. Figure 2 is a photograph of a linear array of ten piezopins mounted on a carriage attached to Gantry A. The piezopins are spaced 10 mm apart, and individually they can be connected either as receivers or transmitters. Each piezopin is spring-loaded vertically, so that by moving the Z motor down, we can achieve consistent coupling with a solid physical model.

Transmitter and Receiver Electronics

Customized circuits were built to select and activate particular transducers in the transmitter and receiver arrays. These circuits were designed to interface with a desktop computer so that they can be controlled by software. A piezopin used as a seismic transmitter is driven by a circuit that generates a high-voltage square wave with a very high slew rate on the falling edge (the voltage falls from 325 volts to zero in less than a microsecond). The piezoelectric element responds to the sharp decrease in voltage by producing an acoustic pulse with dominant frequencies in the range 0.2 to 1.0 MHz. A piezopin used as a seismic receiver senses ultrasonic vibrations and produces a voltage signal proportional to the vibration pressure. Received seismic signals are typically amplified 1000 times and then routed to an A/D board (installed in a desktop computer running Windows XP) for digital recording. The A/D board has two input channels and can digitize each channel at a rate as fast as 25 megasamples per second with 14-bit precision.

Motion Control and Acquisition Software

The linear motor controller board and the A/D board are designed by their respective manufacturers to be installed in PCI slots within a desktop computer. Both boards come with software development kits (SDKs) for the Visual Studio Integrated Development Environment. We used these SDKs to develop a master control and acquisition program in the C/C++ language. The master program defines and synchronizes essential functions needed for automatic seismic surveying: motion and positioning control, selection and activation of transmitting and receiving transducers, digitization of seismic traces, and output of seismic data to SEG-Y files with acquisition/geometric information in the trace headers. The program accepts minimum, maximum, and increment values for the X, Y, and Z coordinates, and moves transducers systematically over the physical model while recording seismic traces.

Model Field Data Examples

Figure 3 is a schematic diagram of a model simulating a marine-type survey using an array of piezopin transducers. The horizontal dimension is about 400 mm. The depth of the water to the top and bottom of the phenolic body is about 80 mm and 135 mm. We moved the array from left to right in 2 mm increments over the centres of the targets, covering a total distance of 300 mm in the Y-direction. Common offset gathers were recorded with receiver #1 which is part of the moving linear array. Source-receiver offsets in the array range from 10 mm to 80 mm in 10 mm steps. As well, common receiver gathers were collected for each shot with receiver #2, at a fixed position offset 20 mm from the line.

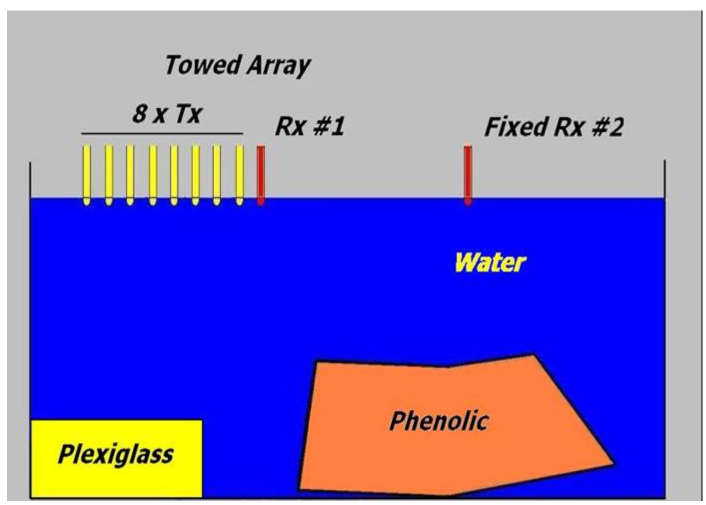

Figure 3: A model marine survey, with eight transmitting (Tx) and two receiving (Rx) transducers.

Figure 4 shows a common offset gather (the offset is 40 mm) taken from the model survey. The transmitting and receiving piezopins in water give seismograms with narrow pulses less than 10 μs long and a dominant frequency of about 1 MHz. The reflection from the top of the plexiglass body appears on the left edge of the displays at a time of about 155 μs. The reflection from the bottom of the container holding the water occurs at about 180 μs. On the color-coded display with AGC applied, we can clearly see diffractions from the corners of the two solid bodies. Figure 5 shows eight different common receiver gathers associated with the fixed receiver Rx #2 and the eight different transmitting transducers on Figure 3.

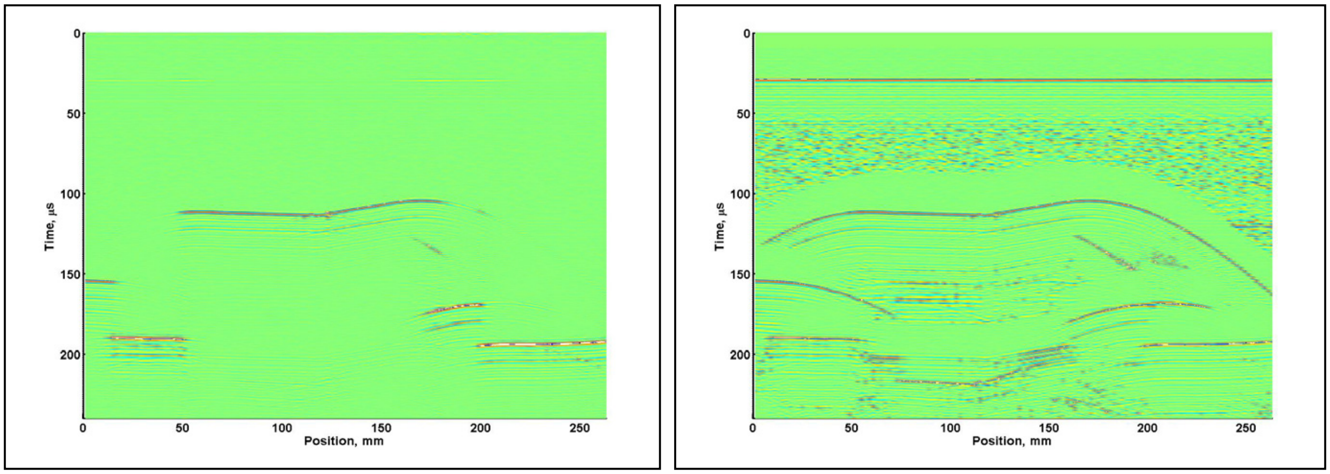

Figure 4: Common offset gather (offset = 40 mm). Left display is normalized color-coded format; right display is AGC color–coded format. With AGC, the diffractions due to sharp corners on the plexiglass and phenolic bodies become evident.

Discussion

Detailed examination of the common receiver gathers on Figure 5 indicates that, while the waveforms of the primary reflections are reasonably consistent from one transmitter to another, the character of multiples and events coming from below the top of the phenolic body vary noticeably from source to source. The reason for this variability may be differences in the piezoelectric characteristics for different transducers, coupled with subtle differences in the mechanical mounting of the transducers. The waveform variability in the gathers may be decreased by deconvolution. However, it is likely that a procedure for selecting transducers with well-matched responses will be required for better results.

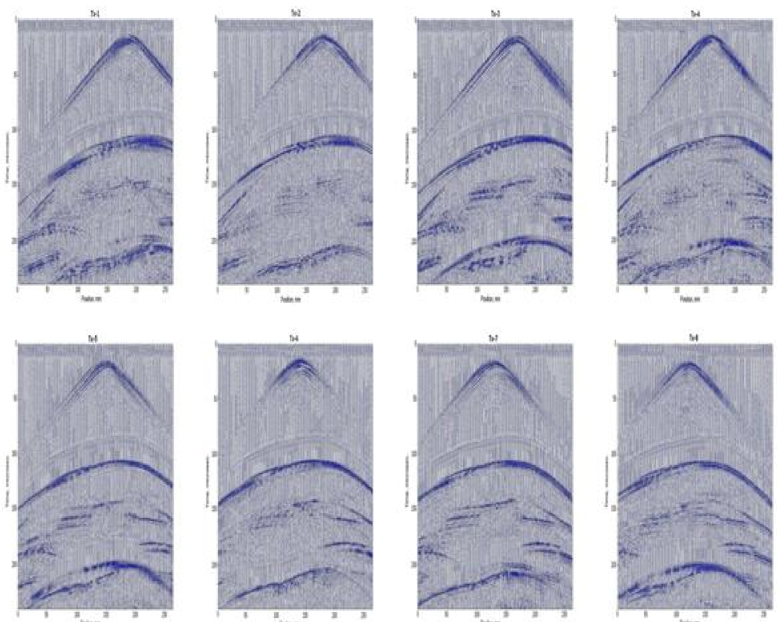

Figure 5: Eight common receiver gathers taken with eight different source transducers and the fixed receiver Rx #2 (Figure 3).

In its current state, the modeling facility can collect up to 2000 traces per hour. For simulating high-resolution 3D surveys, we expect to collect datasets on the order of 10^5 to 10^6 traces. To decrease the survey time for such large datasets as much as possible, we want to increase the acquisition rate to 10,000 traces per hour. We will continue to modify and upgrade the hardware and software for the facility in order to achieve this rate.

Acknowledgements

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References

Cheadle, S.P., Bertram, M.B., and Lawton, D.C., 1985, A physical seismic modeling system, University of Calgary: Current Research, Geological Survey of Canada, Paper, **85-1A**, 149-153.4