# FRx Tiltmeter Services

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The act of injecting material into the subsurface, especially the creation of fractures that open gaps or new space within the soil / rock, causes deformation of the surrounding media. The accommodation of these changes extends in all three dimensions. At the ground surface, the changes are manifest as slight variations in elevation and angle of the ground surface relative to gravity. Measurement of these shifts provides data from which the form – the extent, orientation, and elevation – of the underlying fracture can be inferred.

Requisite tilt data can be collected in real time by deployment of sufficiently precise tiltmeters and a data acquisition system that has the capability to process and record the signals from the tiltmeters. Applied Geomechanics Inc. of San Francisco makes the “Cadillac” of tiltmeters. Their Series 700, which measures tilt along two axes, and their Series 800, which are uniaxial, can resolve 1 μRadian or better.

Series 700 (left) & Series 800 tiltmeters

Both Series 700 and Series 800 tiltmeters are weatherproof boxes with 50-ft long service cables. The tiltmeters are distributed to several locations around a fracturing well and the cables routed to central locations. FRx has constructed weatherproof containers for the analog to digital convertors (ADC) and power supplies (lead acid batteries) to which the tiltmeters are connected. The containers, in turn, are connected to a computer that logs and displays data.

Hydraulic fracturing involves the use of heavy construction equipment, including GeoProbes, forklifts, heavy trucks and the frac rig itself in addition to a variety of smaller but equally vigorous pumps, pressure washers and the like. Isolating the tiltmeters so as to avoid physical damage from these machines as well as suppressing vibration and noise can be difficult. The length limitation imparted by the 50-ft cables places tiltmeters and ADC containers near the well – the center of action. The desire to collect spatially symmetric data often places tiltmeters near vibrating equipment. The implications of these placements can be managed by use of filters in data processing.

Each tiltmeter needs to be essentially horizontal and mechanically stable, which can be a challenge at most fracture sites. The ground surface at job sites varies and can include grassy vegetation, rutted dirt, and broken asphalt as well as more regular paved surface. Rarely will these surfaces be horizontal. We have placed the tiltmeters on top of piles of loose sand or upon bags of sand, but this option is not sufficiently stable to resolve angels finer than 10 μRadians. For more precise work, tiltmeters need to be placed on solid objects. If solid paving is not available, solid temporary pads need to be constructed.

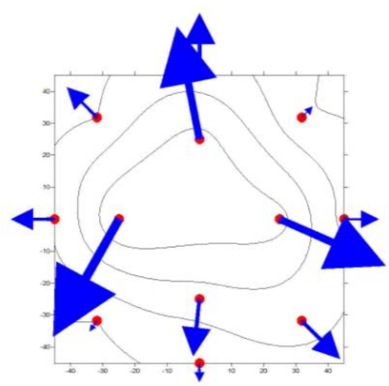
The demands of the data acquisition system are more complex. The AGI tiltmeters are analog devices that output voltage signals within the range of -10 to +10 volts. AGI provides calibration data to convert voltage to angles, with 0 volts corresponding essentially to a truly horizontal device. Tilts caused by fracturing activities are computed by comparing angles generated through time to the initial angle. Thus the tilt dataset also needs to contain the timing of fracture events.

The speed of data collection is driven by the uses of the data. For fracture characterization, the difference between initial and final reading might be sufficient. However, most customers expect the tilt data to provide real time signals of fracture characteristics or real time monitoring of surface and structure deformation. Accordingly, the view of the data needs to refresh every few seconds. This implies, for half hour fracturing events, datasets containing hundreds if not thousands of records. Such intensity of data also assists in identification of mechanical disruptions, such as a bumped or kicked tiltmeter, that nonetheless do not terminate generation of viable data.

Data should be collected under protocols that permit real time display of trends for each tiltmeter, logging or storage of the data for future recall and processing, and interface of data to contouring applications, such as Surfer®, to provide spatial indication of surface deformation and fracturing effects. The acquisition system needs to have the capability to perform calculations of net tilt change.

Optimally, the analog signals from the tiltmeters are converted to digital streams by 16-bit multi-channel ADC's. Presently our system utilizes the National Instrument Model 6210 (and its predecessor Model 6215) ADC, which provide a standard USB interface. These ADC's can sample 16 channels (single end) at rates up to 250,000 Hz and offer programmable voltage ranges for maximum sensitivity.

Given the unique requirements for the data stream, as discussed above, FRx has commissioned a proprietary tilt data acquisition and review application on the Microsoft .net platform. The FRx tilt package integrates (1) tiltmeter calibration data, (2) tiltmeter location data, and (3) the ADC configuration (which tiltmeter on which channel, etc) along with the signal stream to prepare real time displays of net tilt, log the data, and auto- refreshed Surfer plots of contoured tilt magnitude. The package also can retrieve the logged data and subject it to scaling and editing prior to sending to Surfer and generating report-ready graphics. This package can run on an IBM Thinkpad – a 700 MHz P3 antique of a machine.



Example of real time display of surface deformation. Arrows indicate magnitude and direction

The collection of tilt data involves the following steps:

- Deployment of the tiltmeters at planned locations.
- Setup and activation of electronics.
- Manual leveling of tiltmeters to generate a mid-range (horizontal) signal.
- Observation and logging of static tiltmeters to obtain a priori angles.
- Continued observation and logging along with computation of net tilt and contour plotting during creation of a fracture.

The deployment, setup and activation, and leveling requires about 45 minutes for fifteen tiltmeters. This duration does not include the time spent designing the array of uplift locations, which should be tailored to each fracture. Observation of a priori angles should be sufficiently long to establish a convincing baseline. This might be a short as two minutes for a securely placed tiltmeters that are being used to observe a ten-minute fracture. For larger fractures and less certain settings, longer times are appropriate.