Benefits of point acquisition in China: case studies from MEMS-based accelerometers

LV ShuYing* and Denis MOUGENOT, Sercel; LIU Junjie, CGG

Summary

In the domestic market of China, main seismic contractors adopted MEMS-based accelerometers as early as 2004 to perform 2D and 3D high density point acquisition. Compared with the previous conventional surveys based on string of geophones and low trace density, the main benefits were higher signal-to-noise ratio and improved vertical resolution. The better amplitude preservation came as a good surprise particularly for prestack data at far offset (AVO). Three case studies to which CGG and Sercel contributed are selected to illustrate the range of benefits obtained from 2D and 3D point acquisition in China.

Introduction

Point-receiver land acquisition where single-sensors are recorded individually, thus replacing multiple geophones summed electrically, has become economical since the early 2000s' with the development of high-channel-count recording systems and digital sensors. These sensors result from the assembly in the same housing of a Micro Electro Mechanical System (MEMS) with the associated digitizer to generate a direct digital output. They are accelerometer-based devices as opposed to the geophones that are velocimeter-based above their resonant frequency. MEMS-based accelerometers are characterized by very tight specifications. Compared to geophones, they display a linear amplitude and phase response over a wide frequency range (from DC to 1 kHz) and a lower distortion (-90 dB). They are insensitive to tilt, for which they can be corrected (at least for the 3C MEMS sensors). Equally important is the fact that MEMSs are insensitive to environmental variations due to temperature changes, electro-magnetic perturbations, or simply aging: when they deliver, it is always within tight specifications.

As a result of the use of these single sensors together with high-channel-count recorders, significant benefits are obtained. From the operational point of view, less single sensors are used than the number of geophones in the receiver lines. The reason is that digital summation (via group forming or via direct migration/stack) is more efficient in enhancing the signal than the simple analog electric summation of the geophone groups. Even in difficult terrain conditions, like in the 2D comparative test presented below, a single one-component MEMS-based Digital Sensor Unit (DSU1) may replace six geophones. Beyond the significant weight reduction (each geophone with its associated cable and connectors weighs 550g compared to a DSU1 with its electronics that weighs 375g) is the fact that less manpower is required for transportation and planting. The integration of the MEMS with the digitizer and the DSU1s themselves in connector-less Links even further reduce weight and ease deployment.

Figure 1: Comparative 2D test over a loess plateau between MEMS-based accelerometers and arrays of geophones. A single 1C Digital Sensor Unit (DSU1) replaces 6 conventional geophones.
Benefits of point acquisition in China

Performing point-receiver acquisition with MEMS-based accelerometers also provides significant benefits from the geophysical point of view. Even if ambient and source noise is not attenuated as it is the case for an array of geophones, the denser spatial sampling by the single sensors will preserve noise better from aliasing. Thus, processing will be able to remove this noise without affecting the signal. The signal itself is also preserved better, particularly at the high frequencies that are not attenuated during summation by intra-array statics as it may occur between geophones. With MEMS-based accelerometers, the response is extended to the low frequencies that are not attenuated like they are by the geophones below their resonant frequency (10 Hz). However, improvement in the low frequencies was not as large as expected due to the explosive source limitation.

As a result of the combination of high trace density and single-sensor recording, many successful case studies were published showing improvement in the vertical resolution thanks to wider frequency content and a better signal-to-noise ratio (Wang et al., 2008, Liu & Mougenot, 2009). However, another less-emphasized benefit is related to the improved amplitude preservation of both pre- and post-stack data (Shi, et al., 2008 & 2009). Even though this benefit is more difficult to demonstrate on seismic sections, it is of paramount importance since amplitude is the main input used for reservoir characterization via AVO and inversion.

The many 1C or 3C, 2D or 3D surveys achieved in China with these MEMS-based accelerometers cover a full fold area of several thousands of linear and square kilometres, mainly in the northern and the central part of China with Sichuan and Ordos basins being the most surveyed areas. All acquisitions were performed with explosive (up to 10 kg) recorded at a sampling rate of 1ms. The receiver interval was from 5 to 50m, and a live spread requiring up to 11,520 3C RP’s was used. The resulting 3D trace density was from 105,000 traces/km² for the early surveys up to 7.2 million traces/km² for the latest's.

Figure 2: Comparison of pre-stack time migrated data after AGC 1000ms and bandpass Filter 8-12-60-70Hz. DSU1 data not only provides better shallow resolution on near surface due to the denser spatial sampling, but also improved signal-to-noise and vertical resolution on the whole section down 2s twt.

Figure 3: Comparison of pre-stack time migrated Common Receiver Point (CRP) gathers. Not only the vertical resolution, but also the consistency in the amplitude variation with offset (AVO) is better with DSU1.
Benefits of point acquisition in China

2D comparative test in the Shaanxi province (NE China)

Many comparative 2D tests performed in China confirm the benefits of using MEMS-based accelerometers instead of large groups of geophones. During a recent test completed over a loess plateau in the Shaanxi province, four DSU1s every 5 meters replace 24 geophones connected every 20 meters to a digitizer (Figure 1). The source corresponds to single hole explosive shot split-spread every 20 meters at the middle of two 7.2km long active lines: one is composed of 1,440 DSU1 stations, the other of 360 geophone stations. The corresponding shot-points (Figure 1) display bad signal-to-noise ratio and dispersive ground roll as expected in such area.

After significant elevation and tomo-statics corrections, integration from acceleration-to-velocity is performed on DSU1 data via 0-phase surface consistent spiking deconvolution. Prestack time-migration is completed for all individual DSU traces to form CRP gathers at 10m interval similar to those coming from the geophones. Comparison of the migrated sections confirms the advantage of DSU1 data due to improved vertical resolution and signal-to-noise ratio, even below 1.5s twt (Figure 2). For single-sensor acquisition, prestack time-migration of each individual sensor is a critical step in enhancing the signal as shown by the CRP gathers after residual move-out corrections (Figure 3). DSU data displays more consistent reflections from near- to far-offsets, while geophone data gets often attenuated at far offset. This comparison confirms that point receiver acquisition based on MEMS-based accelerometer better preserves amplitude opening the way to improved reservoir characterization.

3D high-density point acquisition survey in the Junggar basin (NW China)

Oil production in the Junggar basin (XinJiang province) comes from shallow Tertiary layers. The Paleogene formation holds the main reservoir that is 3-5 m thick. Oil distribution is controlled by faults some of them with small throws (<10 m). Imaging this reservoir would require the dominant frequency to be at least 60Hz, a target inaccessible to conventional seismic based on geophone strings. In the winter of 2007, BGP on behalf of PetroChina shot a single sensor high density 3D survey (180km² full fold) overlapping old ones (Figure 4).

Che 89 spread was made of a total of 4,608 live DSU1 at 20m spacing. More than 10,000 shots were recorded every 40m along source lines perpendicular to the receiver lines. The resulting fold was 96, bin size 10m x 20m and trace density 480,000/km², up to 30 times more than the previous 3D surveys. Comparison is done with Che 38 a conventional 3D shot in 1991 using 240 channels, 25m x 75m bins, full fold 30 and a trace density of 16,000/km². Pre-stack time migration displays a large improvement in vertical resolution related to the different bandwidth of the two datasets. In addition, the small faults as well as the large reverse fault are better imaged which is related to the improved trace density and better signal-to-noise ratio even at deep levels (Li et al., 2009; Liu & Mougenot, 2009).

The better vertical resolution made it possible to display more stratigraphic details. The negative bright spot that corresponds to the oil-water contact (OWC) is well imaged. Its flatness is more apparent and it has a larger extension than on previous seismic. On the amplitude map of the reservoir interval, the relationship between bright spots, fault distribution and the productive wells is now made obvious.
Benefits of point acquisition in China

3D-3C high-density point acquisition survey in the Shengli oil field (E China)

Shengli oil field lies along the Bohai bay and it is the second oil field in China (194 million bbl in 2011). It is produced from highly faulted and heterogeneous deltaic formations that have been explored for the last fifty years. More than 30,000 km² of full fold 3D have been shot to date over this mature oil field. High density 3D seismic is now required to identify thin reservoirs (<10m), subtle stratigraphic and structural traps as well as deep horizons (>3000m). 3C data are important for sand-shale discrimination and better reservoir characterization.

LuoJia 3D-3C (30km² full fold) was acquired in 2009 by Sinopec Shengli in a flat but densely populated and industrialized area. The active spread was made of 11,200 3C Digital Sensor Units (DSU3) at 12.5m interval to avoid ground roll aliasing (Zhao et al., 2011). Shot points were every 25m. The resulting bin size was 6.25m x 12.5m, the full fold 280 and the trace density up to 3.6 million/km². Each 3C shot point recorded at 1ms was 920MB and the total amount of data acquired was about 30TB which required an upgrade of the processing capabilities.

Frequency content above the main unconformity (1.8 - 2 s twt) was extended from 60-70 to 80-100Hz. Compared to the previous 3D seismic shot in 1990 (240 channels, 25m x 50 m bins and fold 30), improved horizontal and vertical resolutions made it possible to better evidence the stratigraphic relationships between the different sedimentary sequences (pinch-outs) as well as the small faults (throw <10m) sealing the thin Paleogene limestone reservoirs (Cai et al., 2011).

The correlation with well data was significantly improved not only for lithology but also for fluid contents. At the level of the gas reservoirs, better AVO effect preservation resulted in a straightforward relationship between the magnitude of the flat-spot anomalies and the fluid content (high amplitude for gas, low for water and intermediate for a mix). This was not the case with the previous 3D based on low density acquisition (24,000 traces /km²) and geophone arrays.

Conclusion

From numerous 2D and 3D production surveys and comparative tests completed in China with MEMS-based accelerometers such as DSU1s, it has been possible to generate sections which provide better vertical resolution. Depending on terrain conditions and the increase in trace density, the signal-to-noise ratio was also improved compared to conventional acquisitions based on groups of geophones. After the migration of all single-sensor data, these advantages increase. On prestack data, amplitude is preserved better, particularly at far offset with enhanced AVO attributes. Together with enhanced vertical resolution, this open the way to more accurate reservoir characterization and confirms the added-value of MEMS-based accelerometers.

Acknowledgments

The authors would like to show their appreciation to Sinopec and PetroChina, their related geophysical companies and research institutes for their decisive support in unravelling the benefits of point acquisition in China. Their expertise in acquiring, processing and interpreting data coming from MEMS-based accelerometer significantly contributed to the acceptance of this new technology worldwide.

References

Li, J., Hua, Y., and Xu, F., 2009, Advantages of point acquisition high density 3D using digital sensors: a case study from the Che89 well area of the Junggar basin (China): CPS & SEG meeting, Beijing, expanded abstract.
Shi, S. et al., 2008, Digital point receiver seismic acquisition and pre-stack reservoir characterization at Sulige gas field, China; 70th International Conference, EAGE, Roma, expanded abstract A032.
Shi, S., Du, Y. et al., 2009, Seismic acquisition with digital point receivers and prestack reservoir characterization at China's Sulige gas field: The Leading Edge, 324-331.
Zhao, D., Han, W., and Chen, W., 2011, Spatial anti-aliasing and noise cancellation in Luojia 3D HD survey design: SPG-SEG Shenzhen.
Wang, M., Li, H., Zhang, Z., and Li P., 2008, The application of DSU1 high density 3D in coal field exploration; 78th Annual international meeting SEG, Las Vegas, expanded abstract, 1157-1161.