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Multivessel Coil Surveys in the Gulf of Mexico - Current State of the Art and Future Directions

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SUMMARY

A unique multiple-vessel coil seismic survey design has been used to acquire over 12,000 sq km of data in the Gulf of Mexico since 2010. The surveys were designed to improve upon the existing wide- and multiazimuth data sets by recording full-azimuth, high-fold data with offsets in excess of 12 km. The Dual Coil Shooting configuration uses four vessels (two receiver vessels with sources and two source-only vessels) sailing in 12.5-km-diameter circles; with long offsets achieved by sources shooting across the coils. Vessels shoot continuously in a series of interlinked coils that reduces the line change time associated with conventional linear surveys. The coils are placed in a pseudorandom pattern that results in random shot and receiver positions to remove any pattern that may appear in the coverage fold. With the exception of the enhanced noise attenuation scheme (to remove turn noise), largely conventional algorithms and procedures are used in coil processing. Fast-track processing results that compare existing wide-azimuth data sets with the coil data show improved base-of-salt definition and better signal-to-noise ratio.
Introduction

The vast majority of towed-streamer seismic surveys were acquired using a single vessel shooting a series of parallel straight lines. However, an inherent problem exists with this method in that, because the source and streamers are behind the vessel, the seismic raypaths are aligned predominantly in one direction along a narrow range of azimuths. This means that where complex geology is present, such as in the Gulf of Mexico, illumination holes and shadow zones can degrade the seismic image. The solution to this has been the development of wide-azimuth (WAZ) and rich-azimuth (RAZ) acquisition configurations, which typically use a four-vessel crew making multiple passes to deliver better illumination of the subsurface. Although the advent of WAZ acquisition was a step change in seismic imaging, there remain many areas where data quality is inadequate. Modelling studies indicate that a full range of azimuths and long offsets (in excess of 12 km) are needed to image subsalt targets. One way of acquiring full-azimuth towed-streamer data is through the coil, or circle, shooting method that was first proposed by French (1984). In 2009, a unique multiple-vessel circular shooting design was proposed (Moldoveanu and Kapoor 2009) as a cost-effective way to record long-offset, full-azimuth data using towed streamers. The first survey of this type was acquired in the latter part of 2010 and since then, over 12,000 km$^2$ of these data have been acquired using this method (Figure 1). This paper covers some of the design, acquisition, and processing considerations associated with these surveys.

![Figure 1](image1.png)

*Figure 1* Coil survey program in the Gulf of Mexico, the surveys are outlined in blue.

Modelling and acquisition geometry

Many Gulf of Mexico WAZ data sets exhibit areas of poor signal-to-noise ratio and reflector continuity subsalt that are particularly marked where dip is steep and beneath salt overhangs. Unfortunately, these areas of poor illumination are often the areas where the imaging is most critical for identifying drilling targets and for field appraisal. It is intuitively obvious that maximizing the azimuthal coverage of our seismic data sets will improve the image in these cases; hence, the progression from narrow azimuth (NAZ) acquisition though to WAZ and RAZ geometries. Perhaps less obvious is the value of long offsets; however, many recent modelling studies (Li et al. 2010; Cvetkovic et al. 2011) showed that offsets in excess of 10 km can improve the seismic image. A finite-difference acoustic modelling example (Figure 2) was carried out to determine the benefits of full-azimuth, long-offset acquisition compared with a ‘standard’ WAZ design. The model contains a reflector package truncating against a salt keel. In the left image, a commonly used WAZ recording configuration with a maximum inline offset of 8 km and a maximum crossline offset of just over 4200
m was used. It can be seen that the reflector truncation against the salt keel is indistinct using the wide-azimuth vessel configuration. When full-azimuth geometry is used, the signal-to-noise ratio and reflector continuity are improved.

The required full-azimuth, long-offset acquisition is achieved using four vessels, sailing in 12.5-km-diameter circles, with long offsets achieved by sources shooting across the coil (Moldoveanu and Kapoor 2009; Brice 2011). The vessels shoot continuously in a series of interlinked coils, which does away with the non-productive line change time associated with conventional linear surveys.

**Figure 2** Finite-difference acoustic modelling of subsalt reflector package using a linear wide-azimuth survey configuration (left) and using the full-azimuth, long-offset coil design (right).

**Acquisition and survey planning**

At the time of writing, three multivessel surveys have been acquired in the Gulf of Mexico covering over 550 OCS blocks. The survey locations ranged from relatively benign with no obstructions and low currents to heavily obstructed areas with currents exceeding 2.5 knots.

The choice of position and distribution of coils is an important consideration in survey planning and the simplest distribution would be to place coils on a regular square grid or some other regular pattern. However, in these surveys, a pseudorandom coil pattern was applied, which together with the effect of streamer feather, produces a completely random source and receiver point distribution. The motivation behind this is twofold. Firstly, the random shot and receiver distribution removes any clustering or repeating pattern that may appear in the coverage fold. Secondly, compressive sampling theory states that if data are undersampled, the seismic wavefield is better reconstructed if measurements are randomly distributed (Moldoveanu 2010). Seismic data acquired in conventional (non-coil) marine surveys are typically undersampled for both sources and receivers and regularly distributed along parallel lines. Therefore, in any part of the processing sequence that requires interpolation or regularization, these randomly sampled data will perform better than conventional data.

One of the surveys was located in an area where production and drilling installations were present along with associated service vessels and tenders, which affected coil locations. The coil configuration lends itself to undershooting because a single four-boat coil unit can enclose an area with a diameter of approximately 9 km without modification. Careful planning of the coil locations enabled the undershooting of most of the production and drilling facilities without reconfiguration. Three of the larger obstructions in the survey area consisted of platforms and additional service vessels and rigs and, in this case, the coil diameter had to be enlarged to accommodate the exclusion zones (Figure 3). During acquisition, a streamer spread control system was used that automates the onboard control systems to perform intelligent steering of vessels, sources, and streamers, which is of benefit when making close passes to obstructions.
Processing

The departure from traditional linear shooting patterns requires some changes in the way the seismic data are processed. Some of the main differences in the data include high-amplitude, low-frequency noise on the raw data from cross-flow caused by continual turning of the vessels, higher data volumes (over twice the density of linear WAZ data sets), and longer offsets.

The turn noise is predominately low frequency and most noise is seen on the near 1000 to 3000 m of cable due to the higher streamer tension and the fact that the cable motion has a higher crossline component. Where currents are present, the situation changes and position and amplitude of the noise varies around the coil as the crossline component of flow changes (Brice 2011). To address the additional levels of noise, a data-dependent noise attenuation strategy was developed that takes full advantage of the finely sampled point-receiver data (Moldoveanu 2011).

Apart from the aforementioned noise attenuation scheme, largely conventional algorithms and procedures have been incorporated into flows used in coil processing. For multiple removal, 3D surface-related multiple elimination (SRME) is used that benefits from the increased trace density as there are many more traces to choose from for the multiple prediction process. In addition, the position of the sources in the dual-coil design means that there is a near-offset trace for each shot, which also benefits multiple prediction.

All of these data sets were imaged using vertical transverse isotropy or tilted transverse isotropy reverse-time migration schemes that are required for the complex geology and high dips seen in the subsurface. In the imaging process, the method of forming ‘supershots’ (assembling a single shot from several closely located sources to reduce the number of migration operations) is different from a conventional linear acquisition data set. Because the shot locations do not naturally coincide on different vessel passes, shots are selected for this process using a clustering analysis.

Conclusions and future coil designs

Initial survey results show significant improvements over a WAZ survey in the same area. The data show no acquisition footprint, even in the shallow section, and the improved sampling and higher fold significantly reduce multiple content even before 3D SRME demultiple is applied. Figure 4 shows a comparison of the dual-coil data set with an underlying linear WAZ data set migrated using a preliminary isotropic velocity model. We observe an improved imaging of the base salt and reflector continuity of steeply dipping events truncating against the salt body.

At present, we are investigating how the survey designs could be further developed. The use of simultaneous sources has become commonplace in large land acquisition projects and is gaining acceptance in the marine environment. By firing two opposite sources together, the data density is doubled for no extra acquisition cost. The coil design used separates opposing sources in space so, for large portions of a simultaneous shot record, there would be no overlap of the wavefields. It is expected that a ‘passive’ separation technique (one that relies on the imaging algorithm alone) could be used to process the data. Although offsets of 14 km are long by today’s standards, processes such as full-waveform inversion can make use of even longer offsets (16 km plus). This would be achieved...
using larger diameter coils and an additional (fifth) source vessel combined with simultaneous shooting to ensure an even distribution of offsets.

The survey design described here was planned to address some of the imaging challenges in the Gulf of Mexico, but the technique is also applicable in other difficult-to-image areas around the world, such as where thick layers of basalt are present, or where carbonates distort seismic raypaths. We expect to see more surveys of this type carried out in the Gulf of Mexico and elsewhere in the near future.

![Figure 4 Linear WAZ dataset (left), dual-coil data set (right). Both data sets are fast-track wavefield extrapolation migration volumes migrated with the same velocity model. The coil data set shows improved imaging of base salt as predicted by modelling.](image)

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**References**


