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SEISBIT® 3D: the new Seismic While Drilling data acquisition system

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Abstract - The acquisition of 3D seismic data, while drilling, requires an *ad hoc* recording system because of the specific operative conditions. The main requested features are: a large number of channels (400-500) with a complex layout geometry of the seismic lines; long recording times (up to 60 minutes) with the necessity to manage on-line a huge amount of bytes; real time processing of the seismic data to be integrated with other information, like the mud-logging parameters. The SEISBIT® 3D system is the evolution of the 2D system. Multiple control units have been introduced for the synchronised acquisition of seismic data and a specific software package has been realised to process not standard signals. The SEISBIT® 3D has to grant a flexible management of the data acquisition because the recording cannot be repeated and the data must be registered following the drilling progress when the bit reaches the depths programmed for the acquisition.

1. Introduction

The SEISBIT® methodology uses the noise produced by a working drill-bit to obtain well monitoring seismic data. The bit vibration is recorded by pilot sensors on the rig and by a seismic line spread on the surface near the well. The cross-correlation between the data acquired by the seismic line and the pilot sensors gives interpretable seismic data, useful to drive drilling plan and for geophysical investigation. This methodology was applied successfully in many SEISBIT® 2D surveys. The 3D surveys have required to improve and to develop the traditional 2D-acquisition system of the SEISBIT® methodology (Miranda et al., 1996).

"While drilling seismic imaging" and local velocity investigation by using the drill bit signal is a project supported by the European Community that aims to demonstrate the application of the Reverse Vertical Seismic Profile (RVSP) methodology in 3D surveys. This application is based on the innovative 3D while drilling system presented herewith and has been developed

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by OGS, ENI-Agip and ProSol. The goal of the project is to map near real time the velocity information in the area surrounding the well, to obtain seismic images and, in general, to increase the availability of geophysical information useful for the exploration.

The system has been successfully tested in the field during a 3D survey in Sicily, in summer 2000 (Petronio et al., 2001).

2. Acquisition problems in Seismic While Drilling

Compared with the traditional seismic acquisitions, the Seismic While Drilling (SWD) presents specific problems with two different aspects: one intrinsically geophysical, due to the recording conditions and one technological, due to the adopted technical solutions (Miranda et al., 1996).

2.1. Geophysical aspects

The noise produced by a working bit is the source of the signal for the SWD system. This signal, recorded on the surface, has a very low signal/noise (S/N) ratio in the depth range usually investigated, so it is necessary to perform lengthy acquisitions to obtain useful information. It is normally used an average record-time of 40 minutes. This time can vary depending on the geological formation drilled by the bit, on the type of the bit and also on the drilling conditions such as the rate of penetration (ROP), weight on bit (WOB) (Miranda et al., 2000). The recording time is limited by the fact that the source, the drilling bit, is moving during the acquisition altering the travelling time to the geophones and generating interference due to phase differences. The raw data set is not directly interpretable, because the seismic information produced by the drilling bit is mixed with different kind of environmental noises. In order to obtain interpretable seismic data it is necessary to cross-correlate the data acquired by the field channels and the source signal.

To properly record the source signal, the best solution should be to put some sensors down-hole, near the bit while it is drilling, though this way is generally not possible. So the source signal is acquired using different types of sensors on the rig, generally piezoelectric sensors named pilots. In the processing phase the recorded pilot signals are corrected, adjusting different signal responses and calculating the travel time of the signal along the drill string.

The result of the cross-correlation can be considered as a traditional shot obtained with the source positioned in the middle point of the penetration interval. The set of data acquired in this interval is called the level.

A While Drilling Survey is represented by a sequence of levels acquired with a fixed distance along two of them. The Vertical Seismic Profile (VSP) of the well, updated to the reached depth, is available in real time without interfering with the drilling operations. It also provides various types of geophysical predictions as helpful information for drilling operations planning.

2.2. Technical aspects and solutions

Differently from other well monitoring systems, SEISBIT® SWD system uses sensors far from the well. Listening stations are usually located along a given direction starting from the well at regular intervals extending for some kilometres. The station numbers and the distances from the well require a telemetric system as in the traditional seismic surveys. The choice of a telemetric line implies that the A/D conversion is near to the sensor, so that all data in digital format are carried to the control unit through a single telemetric cable. The implemented technical solution is based on the old 348 and 368 Sercel Station Units (SU) that are widely used and cheap.

In SWD the data are processed in real time, so it is necessary to make them directly available on the hard disk of the server computer. To perform this task the Sercel control unit is replaced by a personal computer (PC) with a custom board (FUIC) available on the market and manufactured by ProSol Technology. This PC is dedicated only to the data acquisition, while another computer, the server, to which it is connected via an Ethernet network, performs processing and control tasks.

In the 3D survey, the channel number exceeds the capacity of a single acquisition-PC that is about 150-channels using 2 ms sample rate. Therefore, more than one acquisition-PC is needed. OGS has developed and manufactured a device for the synchronisation of the acquisition-PC's. This device is controlled by the server and it is programmable, able to wait for the occurrence of external events. In this way, it is possible to start the acquisition under the control of an absolute clock from a GPS time-receiver. The GPS used to start the acquisition at a stated time is also utilised to compute the time-shift of the down-hole tools. The GPS has a DCF coded output that is recorded on a line channel with the seismic data. The use of multiple acquisition-PC's allows to record a number of channels virtually unlimited.

SWD strictly depends on the drilling progress, both for the signal source type and for the rate and length of the acquisitions. The SEISBIT® system is connected through a serial data line to the mud-logging cabin that provides the real time values of the main drilling parameters. So the system is able to detect automatically when initial depth of the next scheduled level is reached and can start recording or stop if the final depth is outstripped. Moreover, during the level recording it is necessary to check the rig status. The SEISBIT® system allows defining a range of drilling parameters and, in case one of these goes out of range, the system stops the acquisition (Table 1).

The actual drilling operations are often interrupted during mud circulation, pipe addition, bit change and other maintenance operations. All these interruptions are recorded and saved jointly with the seismic data, mostly focusing on those influencing the acquisition geometry, like the bit penetration and the length of the drill string. This length is crucial to compute the delay of the signal travel time from the source to the pilot (Aleotti et al., 1999). The data are stored in a seismic standard format SEGY-like, already adopted by Seismic Unix software (Cohen and Stockwell, 2001). Each channel is written as a descriptive trace header followed by the trace

Table 1 - List of available parameters for the scheduling of a single level

Level parameters
Maximum number of records
Initial and final depths
Initial and final acquisition times (date, hour, minute)
Record length in seconds
Sampling rate (1, 2, 4 ms)
Starting device: server, external Time Break, GPS, or manual
List of channels to exclude
Maximum rate of bit penetration
Maximum difference between bit depth and hole depth (0 in regular acquisition)
Minimum and/or maximum weight on bit
Minimum and/or maximum torque
Minimum and/or maximum number of rotations per minute
Minimum and/or maximum pump pressure

samples in 32-bit floating point (IEEE format). The header has a fixed length (240 bytes) and it is divided in words of 2 or 4 bytes carrying the information on the position and the acquisition parameters of the channel such as sample rate, number of samples, co-ordinates and elevation of source and receiver, trace index in the spread, field record number and the mean values of the main drilling parameters, (rotation speed, RPM; WOB; ROP; torque; bit number and bottom hole assembly, BHA, specifications).

A single level can have a duration longer than 40 minutes and consists of many chunks of constant length (50 seconds) called record (Fig. 1). Each record is stored in a separate file containing all traces registered in the format above mentioned.

The reasons of splitting level in records are various.

Each record starts under the GPS-clock control on all the acquisition-PC's, synchronised, avoiding time shifting between the data recorded by different acquisition-PC's. Too long registrations (several minutes) would contain dangerous time drift between data sets recorded with different PC's.

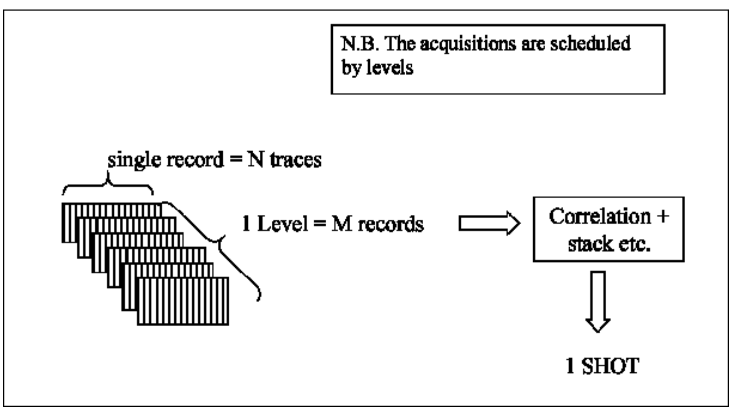

Fig. 1 - Level acquisition scheme.

Before each start of acquisition the system performs a line test, checking whether it is properly working. Data trace length is compatible with programs developed for reflection seismic and not designed for the level length duration (30-60 min). It is easier to control that each record is acquired within the drilling parameter ranges defined for the level, because such short records are simpler to manage. In this way, the level is a set of fixed length records containing only meaningful data. Moreover, in the processing phase, it is possible to stack the correlated data with different weights using the drilling parameters to improve the S/N ratio.

Few seconds are necessary to transfer the data to the server and a new record can start after one minute. This waiting time depends on the configuration: with 170 channels, 2 ms sampling rate, record length 50 s, 2 acquisition-PCs, the waiting time is about 5 s; with 450 channels, 2 ms sampling rate, record length 45 s, 4 acquisition units, the waiting time becomes of about 10 s.

3. Description of the system components

The main components of the whole system are illustrated in Fig. 2.

First, there are basically two categories of transducers: sensors on land around the rig (mainly geophone strings) producing the seismic data and sensors on the rig, producing the pilot

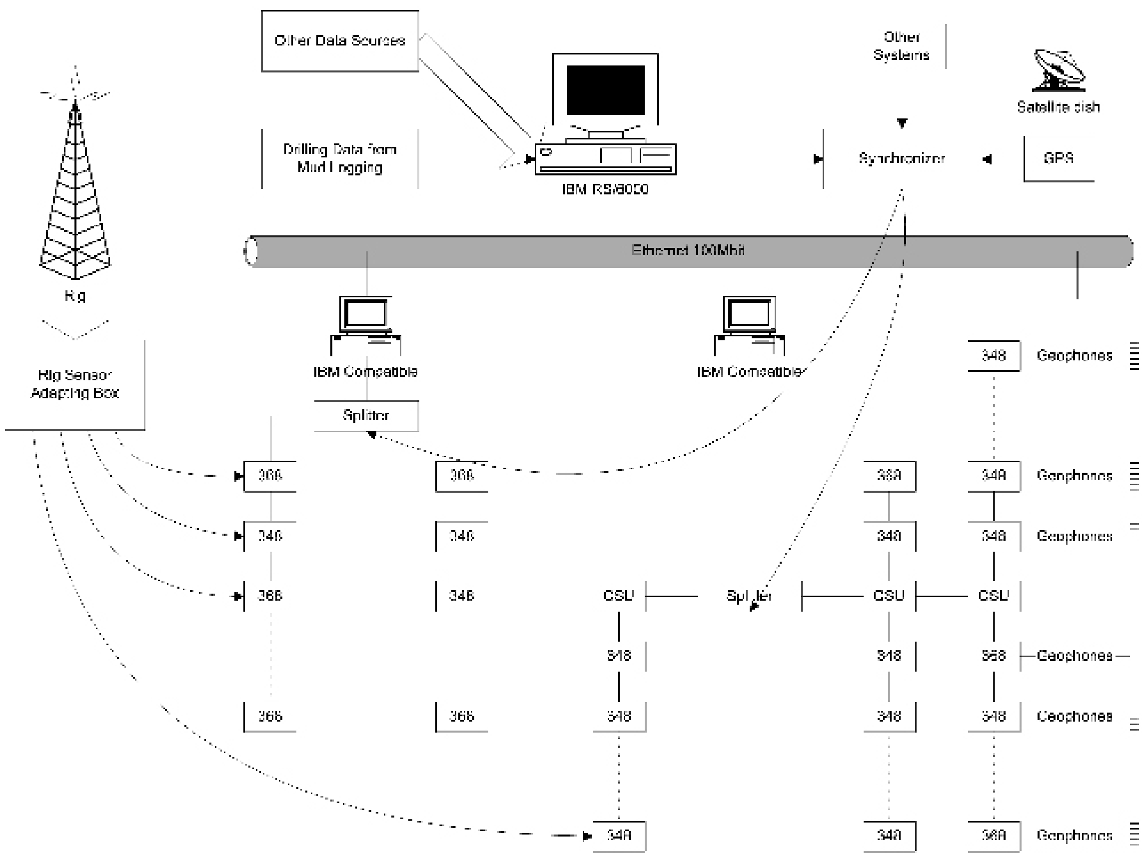

Fig. 2 - Main 3D SEISBIT® system components.

signal for the cross-correlations.

The sensors on the rig are of different kinds and the security norms require connections with special cables and explosion-proof boxes (EX zone). The electrical signal from most of these devices does not match the impedance requirement of the Sercel acquisition line, which is calibrated for geophone strings utilised in traditional seismic, therefore an adapter has been inserted between sensors and the Sercel SU for supplying purposes and signal conditioning. The rig sensors are piezoelectric accelerometer, strain gauges, piezoelectric pressure transducers or geophones. The geophone strings are lined up on the ground mainly moving from the rig, in order to filter the surface noise (Petronio et al., 1999). Most of them are of the same type: double string of 12 vertical geophones, 10 Hz, in linear pattern. Sometime different types of geophones are used, such as horizontal geophones or single geophones, otherwise the geophone string can be placed with not standard pattern.

The effective acquisition step occurs through the Sercel telemetric lines. These lines are formed by a sequence of Sercel SU connected by digital cables. Each SU is composed by four different functional blocks: signal input section (coupling transformer and analog filters), sampling section (the A/D converter), communication section for digital transmission and supply section that powers the circuits. The SN348 SU and SN368E SU have the same behaviour and use the same protocol to communicate with the control unit; for SEISBIT® purposes, the only difference is that the SN368E settings can be configured via software.

Each telemetric line is connected to a control unit, which emulates the Sercel control system. The control unit is a DOS based PC equipped with the already mentioned FUIC acquisition card. The FUIC card is connected to the Splitter (special unit designed by ProSol), which has two input seismic lines.

The Sercel system permits to connect to the control unit either two seismic lines composed by SU’s or two transverse lines, which contain only special units named CSU (Crossing Station Unit) and/or repeater units. Two seismic lines can be connected to each CSU in the transverse line. The same configurations are possible for each acquisition PC equipped with the FUIC card. The acquisition PC, on the right in Fig. 2, is connected to a transverse line. Each line can contain indifferently SN348 or SN368 SU’s and each station can be configured with different parameters such as gain or filter set-up; the only limit is to use the same sampling rate and to set the same parameters for all the SU368 SU connected to the same CSU.

The SEISBIT® system grants a flexible management of multiple acquisition-PC. An Ethernet network connects the PC’s and they are controlled by a set of simple commands. A server computer with multitasking Unix operative system (AIX or Linux) schedules all tasks, performs all control operations and manages output and communication devices such as tape, modem, printer, serial lines.

The field number of each SU can be assigned independently from the position of the channel in the line spread, thus allowing to vary the seismic line configuration during a survey without problems of data reorganisation in the subsequent processing. Each SU can be set passive via software and used as a repeater (multi-gap system).

In case of line failure, the system provides the operators with all the information concerning the failed channel to simplify the troublesome operation of maintenance of the 3D seismic lines.

4. Setting up the survey

After having collected all environmental, geological and geophysical information a pre-survey analysis and modeling is performed. The preliminary design of the surface seismic line layout is verified scouting the site. The recording parameters are chosen according to the drilling plan and to the target depth.

It is necessary to complete the permitting phase (i.e. documentation for local authorities and communication with the owners of the crossed lands) and to conduct a topography survey to position exactly the pegs on the field before physically placing the lines.

If the static corrections to compensate the behaviour of the weathering are not available, it is necessary to perform a static refraction survey.

The on-site installation continues laying out the pilot sensor on the rig, connecting all the lines to the acquisition PC's and connecting the server to the mud-logging cabin.

Now the system is ready to be configured and tested.

The description of the spread must be written on the server in a file that contains the sequence of the channels, each with his own properties: field trace number, SU model, peg number, co-ordinates, elevation, static correction and type of sensor.

The tests on the functionality of the system are described in the next section.

A few records are acquired and the recorded data are used to find the field channels with best S/N ratio, to choose the best pilot for cross-correlation and to tune the recording parameters (number of records per level, distance between levels, record duration).

The operator, using the same preliminary data, estimates the axial velocity in the drill strings and selects the pre-processing parameters.

4.1. Tests and daily controls

It is very important to control carefully that each part of the system is properly working because the drilling conditions during data acquisition cannot be replied: this means that each part has to be tested before a level acquisition and some checks have to be performed even during the acquisition. Herewith a brief description of the adopted tests.

- ***Pulset.*** The proper functionality of the geophone strings and of the whole acquisition chain connected to the acquisition line is granted recording the response to an electrical pulse emitted by the SU and comparing that response with the expected one. This test locates strings not properly working or strings in which some geophone is not fixed to the ground.
- ***TD-test.*** The pulset test cannot be used on piezoelectric sensors, therefore the system is provided with a second identical sensor (named ghost sensor) for each axial pilot, in order to control that the pilot signal is correct. This test verifies the accordance between the recorded data of the sensor and its ghost. Each active sensor on the rig is tested controlling the indicator on its power supply; this test prevents open or short circuits on the rig line.
- ***Noise,*** which measures the electrical noise produced by each SU.
- ***Pulsef,*** which controls the frequency response of the SU filtering circuit.

- ***Status.*** Each channel in the line can be requested by the control unit to send a status word, confirming the proper working of the telemetric line. This test is repeated also during the acquisition.

4.2. Acquisition and automatic pre-processing

The SEISBIT® system allows to schedule a sequence of levels to be acquired and the system can work also during the night in unattended mode. The system is partially fault tolerant: if there are problems in a seismic line (e.g., a SU does not answer, or a cable is cut off), the other acquisition PC's continue to record regularly.

To acquire each level, a set of parameters is prepared and saved in a file (Table 1). The system acquires the levels in sequential order, comparing the drilling conditions received from the mud-logging unit with the imposed parameters. Information about the acquisition geometry such as well and channel co-ordinates, well deviation from vertical (side track), bit diameter and number and BHA number are set once and then used for all scheduled levels.

Each level begins when the drilling bit reaches the programmed initial depth and it ends when the maximum number of records are acquired or the final depth is reached.

Before acquiring each record of the level, the drilling parameters received from the mud-logging cabin are compared with the ranges defined in the level parameter file and the acquisition is delayed until they meet the imposed conditions. These conditions have been introduced because the drilling parameters influence the quality of the seismic signal produced by the bit (Miranda et al., 2000).

The sequential steps of an acquisition are:

1. **line formation** - sequence of commands that each control unit emits through the seismic line to set up the SU's for the acquisition;
2. **starting device selection** - the synchroniser is programmed to start the acquisition with the proper trigger;
3. **line status check** - each SU transmits its status to the control unit to test the line functionality;
4. **multiplexed data recording** - each control unit receives a sample from each SU on the controlled line at every sampling interval;
5. **data transfer** - at the end of every record each control unit sends the multiplexed data to the server;
6. **demultiplex** - the server separates the samples of each receiver channel and writes them trace by trace;
7. **DCF decoding** - the DCF encoded time information is extracted and the exact starting time is retrieved;
8. **trace header editing** - the header (SEGY format) of each trace is filled with the information about the position and the elevation of source and receiver, the recording parameters and the mean value of the main drilling parameters;
9. **Detection of noisy traces** - a diagnostic scan of the data values is performed and the bad

traces are marked;

10. **FFT** - the FFT of the record is calculated and saved to speed up the pre-processing steps.

Steps no. 1 and no. 2 are performed only at the beginning of a new level or after a line failure, while steps from no. 6 to no. 10 are performed by the server during the acquisition of the next record (steps no. 3 and no. 4). This parallelism in the operation flow reduces the waiting time between records and increases the effective recording time.

After the last record is acquired, a set of jobs automatically pre-processes the data of the level.

This pre-processing phase includes the synthesis of optimal pilot traces, cross-correlation, deconvolution, stack, backup, reports and other diagnostic operations. The system permits to add, to remove or to modify the sequence of the jobs that have to be automatically executed.

The results of the pre-processing are available a few minutes after the end of the level acquisition.

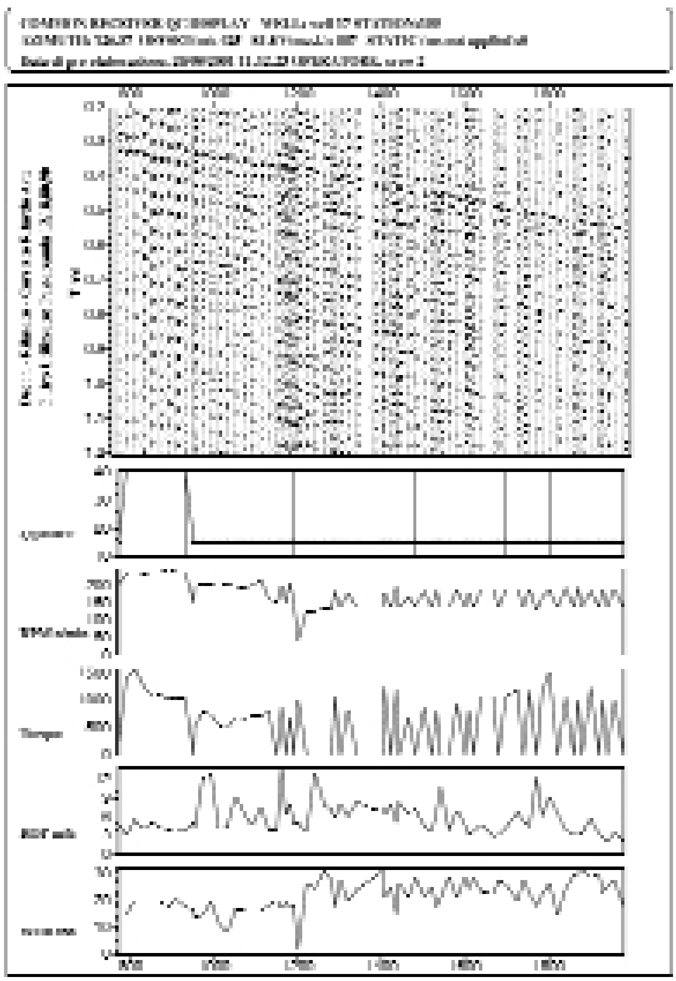

Fig. 3 - Example of quality control display.

5. Interactive data processing

The system provides the operator with a graphic interface to display and process the data.

Some elaboration, specific for the while drilling data, are available in addition to the normal seismic processing. The accelerometer's data are phase corrected to compensate the phase shift related to the geophones. The system allows estimating accurately the velocity of the signal in the drill strings and in the BHA. This velocity is used to compute the travel time of the signal from the bit to the sensor where it is recorded. This delay is applied to the data to obtain a shot with a corrected seismic time scale. The receiver statics are applied to compare the results with surface seismic sections. The first arrivals are then picked and used to separate the up going and down going fields in the VSP processing.

The system has new diagnostic capabilities for the quality control of the 3D data such as not-stacked correlation data, signal-to-noise analysis, statistics of the RMS values. It shows also the time diagrams of drilling parameters that permit the operator to analyse better the well activity during the acquisition period.

The system produces different reports for logging purpose and quality control procedures (Fig. 3). Diagnostic, quality control processing, drilling parameter visualisation and data interpretation are performed interactively by the operators.

From the processed shots different products are obtained such as the near-offset RVSP, 3D RVSP, 3D multi-offset RVSP (Petronio et al., 2001; Poletto et al., 2001, 2002).

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