HPHT cased-hole CCL tool enhancement via DSP techniques for accurate depth control in wire-line well interventions

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Abastract

Down-hole oil and gas operators require a precise depth control method during well interventions. Wire-line technologies using conventional cased-hole casing collar locator (CCL) tools have been proven effective. However, extremely high pressure and high temperature (HPHT) environments make this a challenging task. This work describes a HPHT down-hole tool that use a conventional inductive CCL enhanced by a DSP based electronic module that performs in real-time DSP techniques such as digital filtering and cross-correlation, which permit to store and transmit analog or digital information to a data acquisition system located in the surface. The obtained laboratory tests results of the enhanced CCL down-hole tool, using changes in temperature from 75 °C – 185 °C, provide a firm basis for testing and evaluating the system in the field.

Introduction

High pressure high temperature (HPHT) fields exist around the world; they broadly appear in South East Asia, Africa, China, Middle East, Gulf of Mexico and North Sea. It is expected that a quarter of HPHT operations worldwide happen in American continent and the greater part of them in North America [1]. In this harsh environment, there are important challenges in HPHT development and production that oil companies have identified, and service providers have offered insights concerning existing or planned technologies to fulfill these difficult tasks. One of these key challenges is to attain a precise depth control method during well interventions. Wire-line technologies using conventional casing collar locator (CCL) have been proven effective. However, extremely HPHT environments, beyond 10 kpsi and 150 °C, make this a demanding task.

Usually operators seek for new technologies as the potential problem solvers, in this manner, disregard improvements to older technologies that could offer cost efficient alternatives. In the context of cased-hole CCL tools, two factors have been instrumental in influencing this work. The former is that field cases have been reported of telemetry HPHT tools that provided valuable CCL data to correlate the depth for an intervention [2, 3]. The latter factor is based on availability of high temperature electronic components, which is growing and today is possible to find high temperature passive and active elements, as well as high density integrated circuits such as microcontrollers and digital signal processors (DSP). Particularly, high temperature DSP have made possible to leverage the flexibility not only in electronic designs, but also in the development of algorithms that were not available before. Consequently, DSP integrated circuits allow enhancing field proven techniques such as inductive CCLs.

This work describes a HPHT down-hole tool that use a conventional inductive CCL enhanced by a DSP based electronic module that performs in real-time DSP techniques such as digital filtering and cross-correlation, which permit to store and transmit analog or digital information to a data acquisition system located in the surface. The laboratory attained tests results of the CCL down-hole tool, using changes in temperature from 75 °C – 185 °C, have successfully enhanced the flexibility and performance of CCL detection.

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Description of the system:

The wire-line system is comprised by a Data Acquisition Equipment (DAE) located at the surface installation and a Measurement Tool located at the bottom of the oil well. A KM2 mono-conductor cable is used to provide both the power supply and to communicate the down-hole measurement tool to the surface. The control of the system is performed by a LabView application that runs on the DAE. Figure 1 depicts the general scheme of the application.

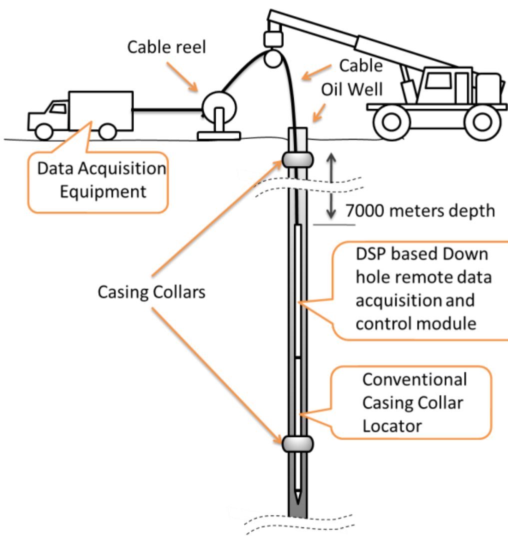

Figure 1. General scheme of application

The DAE supply either an AC or DC voltage for remote powering the downhole tool, and for powering a proprietary Diplexer device located at the surface, which matches both signals to the KM2 coaxial cable. The same scheme is applied to the downhole Measurement tool, which also includes a diplexer that separates the communication signals from the KM2 coaxial cable and matches them to the DSP based data acquisition and control module. The downhole diplexer also matches the power signal from the KM2 coaxial cable to the input of the downhole power supply as shown in figure 2.

The DSP based module is used for data acquisition and control. It is capable of reading not only HPHT sensors, but also acquiring analog signals coming from a conventional CCL. Furthermore, it is capable of processing the acquired data by digital signal processing algorithms as well as storing them in a nonvolatile memory, and sending them to the data acquisition equipment through the KM2 Coaxial cable using a defined bandwidth.

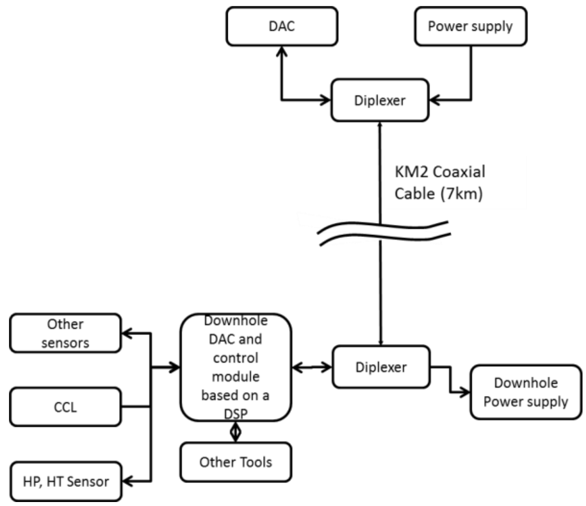

Figure 1. Measurement tool diplexer operation

The data read from the HPHT sensors are stored and sent to the DAE through request by a proprietary digital communication protocol. In the case of CCL signals, there are two ways to transmit them to the surface. The former consists of the acquisition and analysis of the CCL waveform signal, which is carried out to obtain the characteristic signal of a case collar. Then the data related to the event is registered and sent to the surface using the mentioned communication protocol. This method allows the downhole tool to achieve a depth reference signal by registering CCL and sensors data. This permits the tool to work as a stand-alone system for data recording, when it is not possible to communicate with the surface by the proprietary digital communication protocol.

The latter method consists of acquiring the analog signal obtained from the CCL, and transmitting it continuously to the surface into a frequency modulated carrier. This method allows the operator on the surface to see dynamically, in the interface human machine of the DAE, all the details of the CCL signals, and apply his own criteria to count a Case Collar.

CCL waveform and characteristics

The case collar locator is a magnetic device which is sensitive to the increased metal mass at a casing

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collar. The most common current CCL design consists of a coil located between two magnets. A CCL is sensitive to small changes in metal mass. Coils of fine magnet wire with thousands of turns are used in the CCL to obtain a current strong enough to be detected by the data acquisition equipment [3].

In this work, a commercial CCL built by the Mexican Institute of Oil has been used to perform laboratory tests. The output signal delivered by this particular CCL is shown in figure 3.

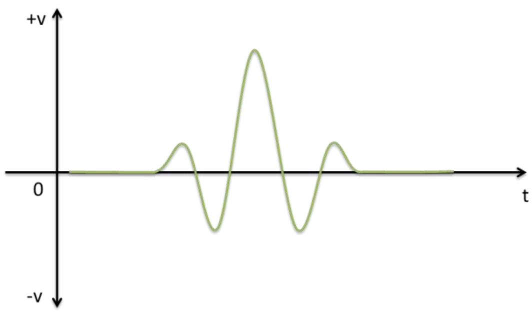

Figure 3.Characteristic output signal delivered by the CCL when it passes through a casing collar

This waveform varies in amplitude and duration depending on the speed at which the CCL passes through a casing collar. The faster the speed at which the CCL pass through a casing collar, the shorter and higher is the absolute value of the voltage amplitude of the signal at its output.

The downhole Data Acquisition and Control Module

The downhole Data Acquisition and Control Module (DAQ), depicted in figure 4, is the principal module of the downhole measurement tool. It is based on a high temperature (210°C) Digital Signal Controller (DSC) from Texas Instruments [4]. It hosts a firmware that comprises a proprietary Power line Communications (PLC) stack, functions for registering and reading data from a non-volatile memory, functions of acquisition of data read from HPHT sensors, as well as functions for the acquisition and processing of the signals generated by the CCL.

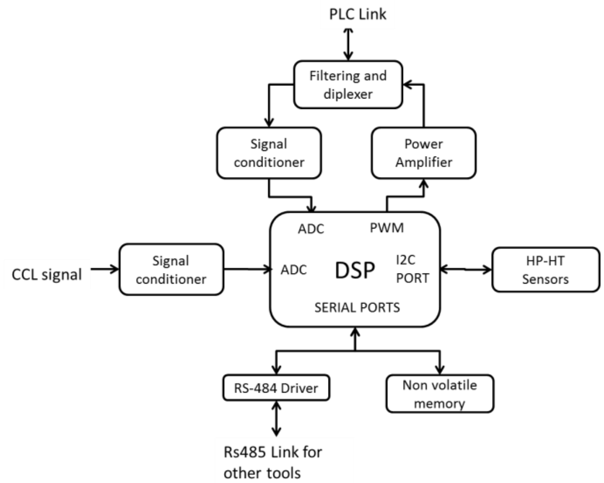

Figure 4. Downhole DAQ module

The architecture of this module has been developed taking into account the availability of electronics devices capable to endure high temperature (+200°C) operating environment.

Cross-correlation method for detecting Case Collars

In this method the analog signal generated by the CCL is steadily acquired by the DSC through an Analog to Digital Converter (ADC). The captured signal is filtered using a Band-Pass Finite Impulse Response Filter (FIR) in order to remove the DC level present in the incoming signals produced by the Signal conditioner, and to increase the signal to noise ratio (SNR).

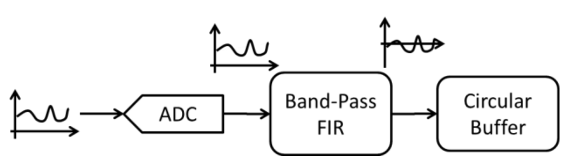

Figure 4. Data acquisition equipment description

The filtered signal is then loaded into a circular buffer with the purpose of applying a cross-correlation function as shown in figure 5.

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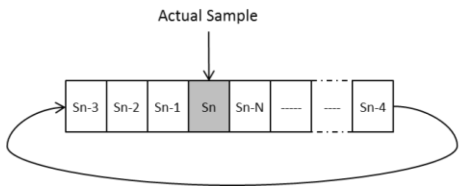

Figure 5.Circular buffer

Where n is the actual value of a data pointer that indicates the position of the actual data read, and N is the length of the circular buffer. The size of the circular buffer is determined by the maximum length in time of the signal acquired from the CCL whose value depends on the slowest speed at which the CCL pass through a casing collar.

The sampling rate is determined by the maximum speed at which the CCL pass through a casing collar as well as the higher frequency components of the waveform acquired from the CCL at the mentioned speed. A reference signal, previously acquired, is first stored in a non-volatile memory.

The reference signal is loaded into an array, which has the characteristic of having the shortest length required to represent the characteristic waveform of a CCL signal expected when it passes through a casing collar. The reference signal has also normalized values of magnitude as shown in figure 6.

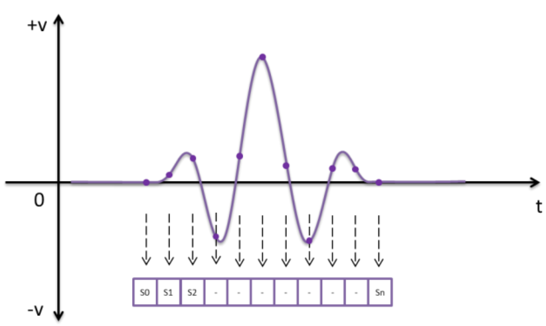

Figure 6. Reference signal stored in memory

The acquired signal coming from the inductive CCL is processed by an algorithm which tries to identify and detect the characteristic waveform of a casing collar. To achieve this, the algorithm employs the cross-correlation function, which is a measure of similarity of two waveforms as a function of a time-lag applied to one of them [5], and is given by

$$(f * g)[n] = \sum_{m=-\infty}^{m=\infty} f * [m] g[m+n]$$

Where f*[m] represents the sampled version of the reference signal, $g[m+n]$ is the sampled version of the signal coming from the CCL, n is the (time) shift (or lag) parameter and $(f*g)[n]$ indicates the sequence being correlated. However, dealing with finite-duration sequences, it may be expressed in terms of finite limits on the summation. For this particular application, the following conditions have been considered:

$$(f * g)[n] = \sum_{m=n-(\frac{N}{2})}^{m=n+(\frac{N}{2})} f * [m] g[m+n]$$

Where: N is the number of samples of the reference array. Because the expected signal to be detected does not have a constant length of time, due to variation in its speed, a single cross-correlation function could not detect the expected signal in all conditions. Thereby, the length range is divided in several discrete values of period and a cross-correlation function is performed for each one as depicted in figure 7.

Each cross-correlation function requires both arrays to have the same size or number of elements; however, the circular buffer does not have the same size as the reference array. The cross-correlation function applied in this work is performed with a variation in the indexing of the circular buffer. The counterpart value of each element of the reference array is obtained through a pointer whose increment is determined by the corresponding discrete value of period being analyzed, and is given by

$$(f * g)[n][k] = \sum_{m=n-\left(\frac{N}{2}\right)}^{m=n+\left(\frac{N}{2}\right)} f * [m]\, g[\left(\frac{k}{P}\right) m + n]$$

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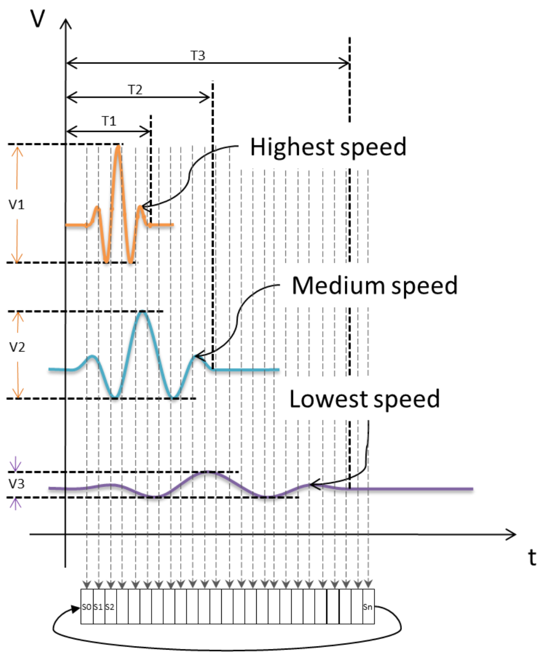

Figure 7. Period of time for different speeds of the CCL tool

Where P is the number of steps, between the fastest signal and the slowest, it is chosen to detect the passing of a casing collar, and k is the particular step in analyses.

Finally, a digital average filter is implemented in order to reduce the noisy effect at the slowest speed's signals, and this is given by

$$(f * g)[n][k] = \sum_{m=n-\left(\frac{N}{2}\right)}^{m=n+\left(\frac{N}{2}\right)} f * [m] \left(\sum_{n-\left(\frac{P}{2}\right)}^{n+\left(\frac{P}{2}\right)} g[M+n] \right) / P$$

$$\mathrm{M} = \left(\frac{k}{P}\right) m$$

Where M represents integer values. The result of each cross-correlation is then compared to a pre-defined threshold. If one of these comparisons is higher than the threshold value, a flag of detection of a case collar is raised. The flag triggers a function that stores the date and time of the detection as well as increases a software counter of the number of case collars detected. Figure 8 shows an example of a slower CCL signal detected by this method.

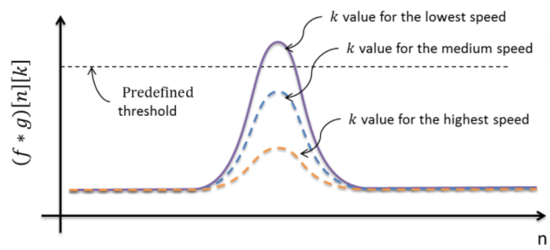

Figure 8. Cross-correlation value and a predifined threshold value

The correlation method was tested satisfactorily in the laboratory by detecting case collar using temperature changes from 75 °C to 185 °C and a multi conductor cable of 6.5 km.

Method for transmitting the analog CCL signals to the surface

To perform the transmission of the analog signal acquired from the CCL, located at the bottom of the oil well, to the DAE, located at the surface, a frequency modulated carrier is used. As first step, the DAQ module acquires the analog signal generated by the CCL. Each sample is processed at the time. The process includes a suppression of the DC level of the signal and a product operation.

The suppression of the DC level is performed by subtracting the constant average value from the acquired signal. The result of this processing is used to control a pulse width modulated (PWM) signal by its control register which determines the output frequency of the PWM. The product operation is performed using a constant value, which has been calculated considering the available bandwidth in the output front-end of the data acquisition and control device as well as the frequency variation per unit of the PWM's control register. The result of this method is a carry signal, or a frequency modulated (FM) signal, whose frequency is directly proportional to the instantaneous read value at the CCL output. The DAE detects the FM signal and demodulates it to recover the value of the CCL output and displays it in real time in a monitor.

The laboratory trials obtained by this method detected correctly case collar using temperature changes from 75 °C to 185 °C and a multiconductor cable of 6.5 km as a communication channel. Figure

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9 shows a typical CCL analog signal displayed in real time at the interface human machine of the DAE.

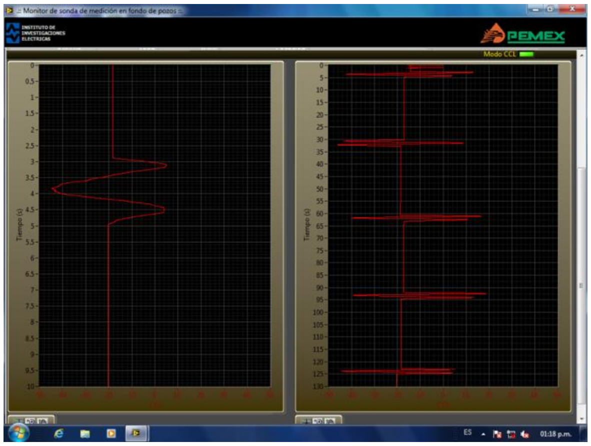

Figure 9. CCL signal displayed in the interface human machine of the DAE at the surface

Conclusions

A HPHT down-hole tool that use a conventional inductive CCL enhanced by a DSP based electronic module has been described. The DSP module performs in real-time two methods for detecting case collars. The former performs DSP techniques such as digital filtering and cross-correlation, which permit both storing in the downhole tool memory the case collar detection and transmitting digital information to the data acquisition system located in the surface. The latter method acquires and transmits continuously to the surface an FM signal, whose frequency is directly proportional to the instantaneous read value of the analog signal coming from the CCL. This system provides facility to the operators, by selecting which method is more convenient during the downhole operation. The results attained in the laboratory using temperature changes from 75 °C to 185 °C and a 6.5 km multiconductor cable as a communication channel have been successful, taking to the authors to the next stage of the work which is the testing and evaluation of the system in the field.

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