Downhole noise analysis and control for microseismic data acquisition in a live well

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Abstract

Recording and interpreting microseismicity provide valuable continuous real-time information about reservoir performance. To ensure close reservoir proximity during microseismicity recording either a dedicated monitoring well has to be available, or a live well has to be shut in. The shut-in costs or monitoring well availability may severely limit the application of microseismics for reservoir monitoring. This limitation can be overcome by recording microseismic events with a properly designed and installed tool inside live and highly deviated wells without the necessity to stop production/injection during data acquisition.

Such a tool must be insensitive to well flow noise to be able to detect the microseismic signals, which are of very low energy. It must also be integrated into the well completion with minor, or prefereably no modifications in order to stay permanently in the well without affecting its functionality.

A tubing conveyed device, hydraulically released downhole at the final depth, clamping against the casing and therefore decoupling the sensors from the tubing flow noise, provides such a solution. Acoustic waves do not propagate through all media with the same efficiency due to loss of energy at each acoustic impedance boundary. The noisy environment in a live well can be managed by controlling the mechanical coupling of the sensing device, thereby significantly reducing the noise level. A new tubing coveyed tool has these attributes through a system of sensors, which are decoupled from the tubing and clamped against the casing. The sensors are therefore largely independent of tubing flow rate providing a noise level consistently below the take-off threshold for the microseismic event population.

The clamping device was deployed and recorded high fidelity microseismic events during a 3 phase acid stimulation job.

Introduction

Microseismicity may provide continuous real-time information about stress changes in the reservoir away from and between wells. These changes are caused by injection and production operations. Mapping the stress changes in both space and time provides a unique insight into the effect of pressure change on the lithological framework and associated movement of reservoir fluids.

To map the impact of oilfield operations on the reservoir rock, a good microseismic sensing system that consistently acquires high fidelity, low-noise data to maximize the located event population is required. To ensure close proximity to the reservoir when sensing low magnitude microseismicity, a downhole solution with a low noise floor is required. When monitor wells are available for installing microseismic sensing systems, this is not an issue. However the limited availability of monitoring wells, especially in the offshore environment, has left microseismic monitoring as a niche technology for reservoir management. This limitation can be overcome by recording microseismic events with properly installed and reliable tools inside live wells with no production/injection stops during data acquisition. Such tools must be insensitive to the flow noise of the well to detect the very low energy microseismic signals. They must also be integrated without modifying the well completions design to stay permanently in the well without affecting its functionality.

Understanding the downhole noise and effectively lowering the noise floor at the sensors are therefore paramount for a successful downhole microseismic sensing system in a live well. By understanding and handling the downhole noise issues a solution for a downhole live well passive seismic sensing system is proposed and illustrated with a case study.

Microseismicity

Pore pressure changes in the reservoir may induce microseismicity either through production or injection by releasing the strain energy stored in the rock. An individual microseismic event provides information about its source and also the rock mass through which it passes in travelling from source to receiver (Wilson et al., 2008). Microseismicity may provide continuous real-time information about the stress changes in the reservoir away from and between wells and mapping these changes in both space and time provides a unique insight into the effect of pressure change on the lithological framework and associated movement of reservoir fluids.

Reservoir related microseismic events tend to be small with slip vectors of a few microns and can be summarized as having the following important characteristics: Detectable microseismic events induced by reservoir operations usually fall into a size range between Mw = -3 and Mw = -1. Larger events are possible particularly in stiff reservoirs that are critically strained. Small magnitude events are abundant but tend to attenuate over very short distances and are difficult to record providing limited information about the reservoir as a whole. The value of microseismic monitoring is related to the size of the detected event population detecting as many events as possible and the recorded microseismic amplitudes usually relates more to the noise-floor of the acquisition system than the level of vibration in the rock.

Downhole noise in a live well completion

Many noise sources exists within a well completion impacting the data acquistion of the microseismic sensing system (Figure 1).

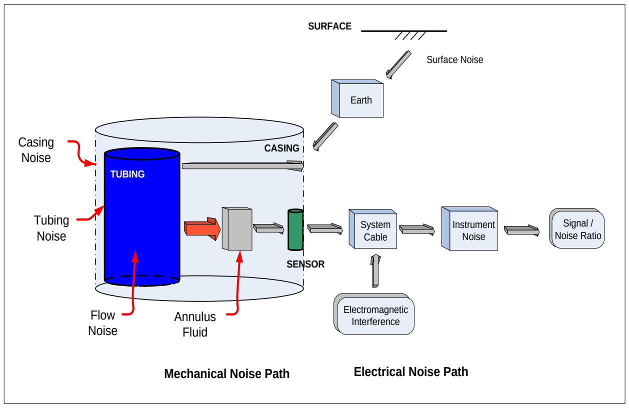

Figure 1: Schematic of the well completion with the different noise sources potentially impacting the sensor.

Noise contamination can be reduced by following the three fundamental design concepts:

- Remove controllable noise sources
- Filter noise that reaches the sensors
- Control the noise propagation

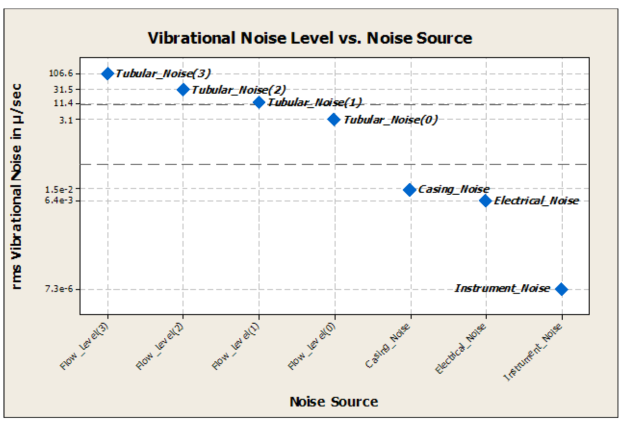

Figure 2: Noise level for geophone mounted directly on tubing with increasing flow rate and compared to casing, electric and instrumental noise. Sensor mounted on the tubing: No strokes = (0) flow rate. 20 pump strokes = (1) flow rate. 30 pump strokes = (2) flow rate. 40 pump strokes = (3) flow rate. Electrical noise converted to u/sec.

Removing controllable noise sources is assumed to be an integral part of the well completion and microseismic sensing project design. Reservoir induced microseismicity has a distinct signature, which makes it possible to filter unwanted signals (noise) and enhance the primary signals. A key task is therefore designing a microseismic sensing system focusing on controlling noise propagation.

In a live well the flow rate in the tubing can be shown to be a major noise source. A sensor mounted on the tubing directly records all noise related to the pump rate, which is significantly higher than other noise sources such as casing noise, instrument noise and electrical noise (Figure 2). Managing tubing flow noise is therefore a main objective when designing a microseismic sensing system.

Sound does not propagate through all media with the same efficiency and loses energy at acoustic impedance boundaries. By controlling the mechanical coupling of the sensing device to any source or path of noise, a very significant reduction in noise can be achieved. Field tests show how sensors placed in different positions in the completion environment responded to flow noise. Figure 3 shows a plot of noise versus flow rate for sensors deployed in various positions downhole and the response during a test. The orange line in Figure 3 shows the response of a sensor mounted on the tubing itself. The green line shows the response of a sensor cemented behind the casing. As flow increases so does the recorded noise from the sensor on the tubing. In contrast the sensor behind the casing shows a limited response to the flow noise and its output remains effectively flat during the test. This relationship shows that noise from the tubing does not propagate to all parts of the completion. The red and blue lines show the response of sensors mounted on two different annular deployment devices. For the red line the device is coupled to the casing using a traditional bowspring. The blue line represents a sensor coupled to the casing using a clamping device detaching the sensor from the tubing. As the flow increases, noise on the bowspring device follows that of the sensor on the tubing. However for the clamping device, the sensor response follows that of the sensor behind casing, where the noise remains low and only increases slightly with increased flow. The difference between the performances of these two sensors is due to the fact that one is mechanically coupled to the tubing and the other is not.

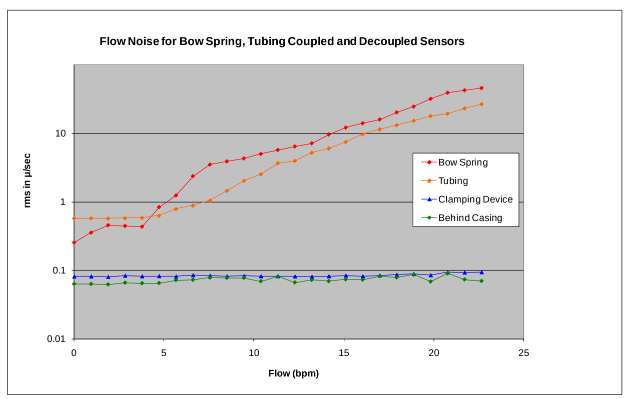

Figure 3: Flow noise recorded by sensors mounted at 4 different locations in the well completion with increasing flow rate.

Live well microseismic monitoring system

The low noise environment behind casing provides a possible location for a microseismic sensing system with cemented geophones. But sensors behind casing impact both the drilling and completion as the hole diameter has to be increased to accommodate the sensors and the casing size has to be uniform for the complete well trajectory. The cost of the microseismic sensing system behind casing is comparable or cheaper compared to other solutions; however the well completion costs increase significantly. Combined with the fact that the system has to be planned before drilling the well does not make this an attractive monitoring solution.

A tubing deployed system which is released downhole and clamping the sensors against the casing and decoupling them from the flow noise, however, may provide such a solution.

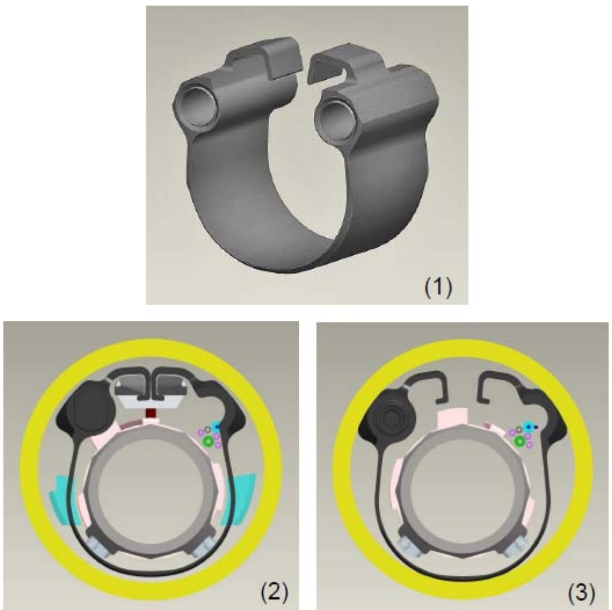

Figure 4: (1) The clamping device in its relaxed state consists of a C-section that is slightly larger than the casing size. (2) When the device ends are squeezed together the outside diameter reduces so it fits inside the casing. (3) The clamping device is shown in its deployed state with the geophone clamped to the casing and decoupled from the tubing.

Figure 4 shows a clamping device called the Omega-Lok, which in its relaxed state consists of a C-section steel fitting that is slightly larger than the casing size within which it is to be deployed (Wilson et al, 2008). When the ends are squeezed together the size of the device is reduced allowing it to fit inside the casing. Once the tubing is in place and set, the clamping device can be released by pulling the fork, which had maintained the ends together (Figure 5). When released it never reaches its full relaxed state and is physically constrained by the casing. The clamping force that it imparts to the inside of the casing is quantified as part of the design process. In the system's deployed state, the clamping device, and the sensors it contains, no longer touch the tubing and have no direct mechanical noise path from the tubing to the sensors.

To validate the sensor decoupling from the tubing noise a deployment test was performed with a reference sensor mounted on the tubing and a sensor inside the clamping device (Figure 6). Background noise was recorded for both sensors during the opening of the clamping device. The noise burst for both sensors are related to the actuation of the fork releasing the clamping device. After the release of the clamping device the background noise level on this sensor reduces significantly compared to the noise level recorded with the sensor mounted to the tubing.

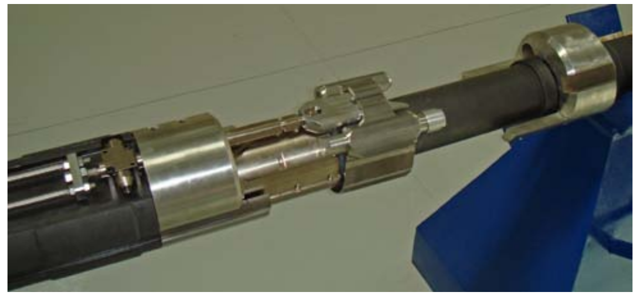

Figure 5: The clamping device in its closed state with a geophone mounted.

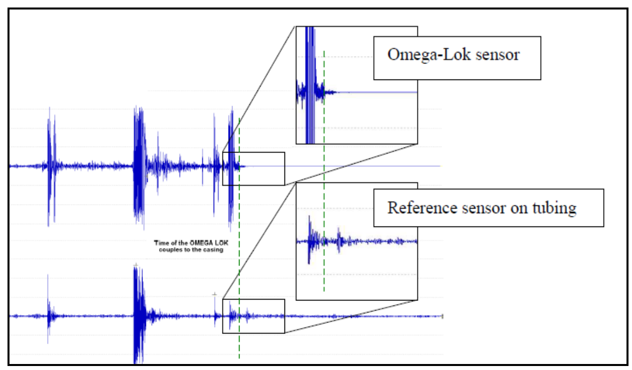

Figure 6: Measured noise from a sensor mounted on the tubing and in the clamping device. Dotted green vertical lines represent the time when the sensor is clamped against the casing. The reference sensor on the tubing is still noisy, whereas the clamping device is quiet.

Example

A dual tool installation inside a producing well recorded microseismicity during a 3 phase well stimulation job. Data were acquired before, during and after the well stimulation and were processed and interpreted. A single well was used for the monitoring, which at the reservoir depth of around 15,000ft was highly deviated. The installation of the microseismic sensing system was some distance above the horizontal reservoir section.

Good quality microseismic events were detected and localized as shown in Figure 7 confirming that the geophone coupling to the casing has been effective and the resulting low noise floor permitting the passage and recording of reliable and interpretable microseismic events.

The development over time of the microseismic events associated with the well stimulation indicates a pathway for the acid fluids away from the reservoir section reducing the impact of the well stimulation. After 2 months the microseismic sensing system was successfully retrieved and a new stimulation strategy is now being considered.

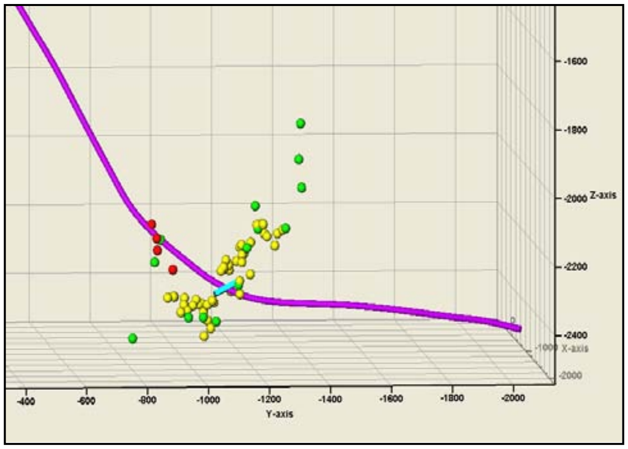

Figure 7: The final processed microseismic events located in relation to the well trajectory. Red dots were the first phase of the well stimulation, green dots the second phase of the stimulation and finally the yellow dots were the third and final phase.

Conclusions

The live well environment is noisy, but the noise does not affect all parts of the completion equally. Recording microseismicity induced by reservoir operations provides important information about reservoir performance, however low magnitude microseismic events require low background noise levels. Due to high flow noise levels inside tubing, sensors mounted on the tubing itself will not be able to detect the microseismic events. However the noise level at the casing is significantly lower making it possible to record microseismicity with sensors either clamped against the casing or located outside the casing. A tool with sensors being tubing deployed and then clamped against the casing provides an operational solution for monitoring microseismicity in a live well without interfering with the well completion.

References

Wilson S. A., Floch G. L., Jones R., 2008: Monitoring the oilfield of the present using live-well microseismic technology. OTC Paper 19693. 2008 Offshore Technology Conference, Houston, May 2008.