Shear Acquisition by LWD Quadrupole Tools : Case Histories

Carlos Francisco Beneduzi, Jorge Alberto Fett Medaglia, Petrobras

This paper was prepared for presentation during the 12th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, August 15-18, 2011.

Abstract

The measurement of shear wave velocity in slow formations always offered difficulties to acoustics logging industry. Wireline tools used successfully dipole sources, however in the logging-while-drilling environment (LWD) the presence of the collar doesn't make feasible the option.

Quadrupole sources were developed to solve the needs for this information. Quadrupole waves are dispersive and guided waves, demanding special care in the acquisition and processing.

This paper presents some case histories were the shear acquired by quadrupole sources doesn't fit with the shear acquired by dipole and monopole sources and discuss the presumable reasons for the differences.

Introduction

Acquisition of shear slowness in slow formations was solved for wireline tools in the later '80s making use of dispersive flexural waves generated by dipole sources introduced in the acoustic tools. The same solution, however, can't be applied to LWD tools. The reason is the presence of collar flexural arrival in the same slowness-frequency band of formation flexural arrivals.

Industry had tried the option of quadrupole technology. Despite the studies with shear measurements obtained by quadrupole methods dating back from the 80's, the first tool with this technology was commercialy introduced in 2002. Quadrupole formation arrivals, thanks to proper design of the collar were maintained apart of the quadrupole collar arrivals and a reliable shear slowess is obtained with the method.

However, the real environment acquisitions had shown that the reliability of the shear it"s not easily obtained. Case histories had shown that the measurement depends on several constraints that not observed can lead to unexpected results.

Method

The presence of drill collar deeply affects the wave propagation inside the borehole. Compressional velocities have been successfully measured however shear velocities, particularly in slow formations, offered serious difficulties to the industry. The first attempt with dipole transmitter had resulted unsatisfatory. There's a strong interaction between the collar and the formation under dipole excitation determining that the signal of the collar and the formation coexist in the most part of the frequency range of measurement. (Fig. 1) Besides, there's a large velocity difference between shear and flexural formation waves.

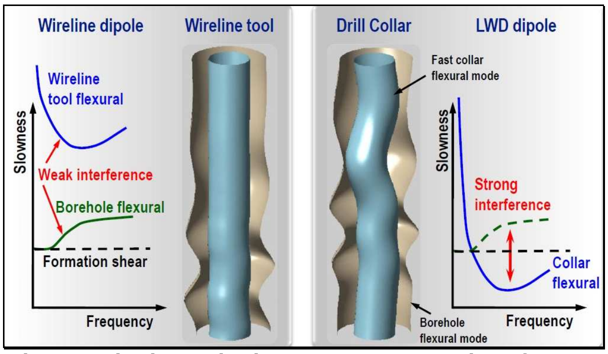

Fig 1 – Dipole excitation causes strong interference between collar and formation signal in LWD tools. In wireline tools the interference is weak. (Schlumberger, 2011)

Then industry focussed his efforts to quadrupole excitation. A quadrupole wave is an interface wave that travels in the fluid annulus, between tool and formation; is also called screw wave; is dispersive and at low frequencies it propagates with the shear velocity as well dipole excitation. However, there's a significant difference in the way that dispersion slopes of dipole and quadrupole modes approaches and reaches shear slowness at lower frequencies; quadrupole dispersion curve.is steeper at that point (Fig. 2). The difference makes the shear identification in the quadrupole mode a process involving diligence once the frequency band where the quadrupole wave travels at shear slowness is narrower than the flexural wave and the amplitude is low.(Fig. 2).

The knowledge of the effects on the dispersion curve to model it correctly and what points of the curve to choose as shear slowness are decisive to obtain a reliable value. Two methods have been developed by the industry to solve the problem: the dispersive slowness-time coherence (DSTC) (Kimball, 1998) and the weighted spectral average algorithm (Geerits and Tang, 2003).

The quadrupole excitation is weaker than dipole, however the tool quadrupole mode has a cutoff frequency higher than the frequencies where quadrupole wave travels at the formation shear velocity, resulting in a weak interference between modes (Fig. 2)

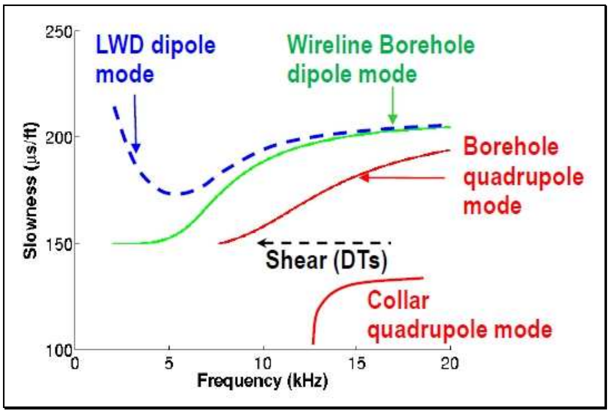

Fig. 2 – Dipole and quadrupole modes have distint dispersion curves and they reach the shear slowness value in a different way. Compared with borehole quadrupole wave, the collar wave is faster and shifted in frequency (Schlumberger, 2011)

Effects on the quadrupole measurement

Tool effect

The presence of collar causes a shift in the quadrupole dispersion curve increasing the dispersion and lowering the cutoff frequency of the quadrupole wave (Fig. 3). More the borehole volume is taken up by the collar more accentuated is the effect, so in slim boreholes and faster formations the effect is stronger than in large boreholes and slow formations.

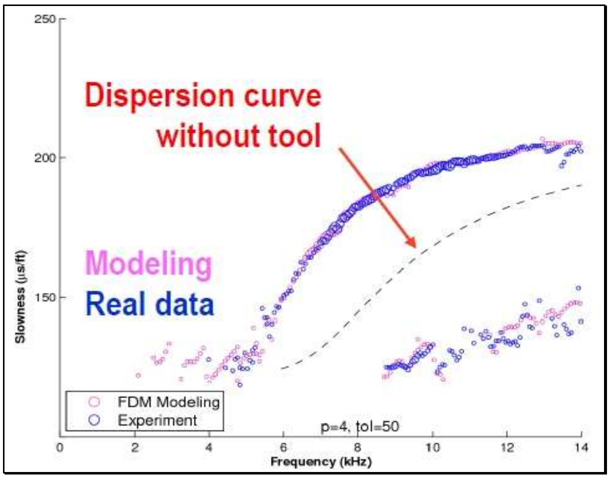

Fig. 3 - The presence of the tool strongly shifts the curve of dispersion (Schlumberger, …)

The ability in modellng how the collar influences the dispersion curve is critical to obtain a reliable shear slowness value.

Tool eccentricity

Tool decentralization shifts the dispersion curve towards lower frequencies; the shift is stronger in fast formations (Fig. 4). If the frequency band of measurement weren't changed towards lower values, a larger dispersion effect will be encountered. Data modeling determined that for eccentering values below 50% of the mud annulus radius, the impact on the dispersion curves and slowness values is less than 1%.

An additional effect of decentralization is the generation of non-quadrupole modes (mainly dipole (flexural waves) and monopole (Stoneley waves) modes). The low amplitude of the waves and the shift in time of Stoneley wave doesn't interfere in the determination of the shear slowness.

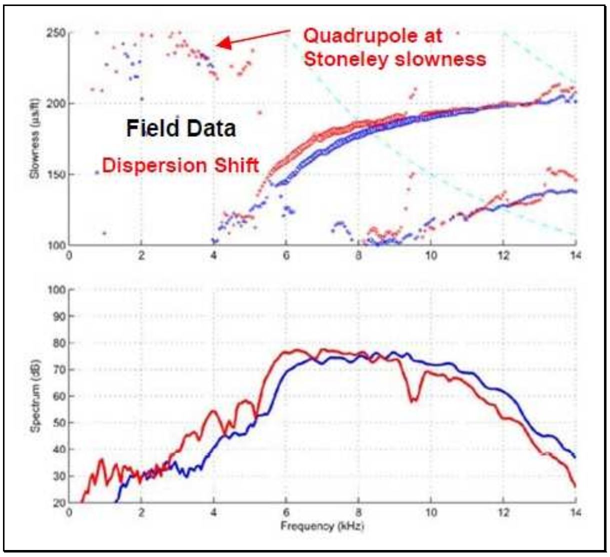

Fig. 4 - Field data dispersion curve and amplitude spectrum for 4.75" LWD tool in a 7" borehole, centralized (blue), totally excentralized (red) (Scheibner et al.(2010))

Drilling Mud Properties

Mud density and, mainly, acoustic slowness, influences the measurement of shear slowness. Heavier muds cause large dispersion. Studies showed that sensitivity of the dispersion curve to mud slowness increases in fast formations and higher frequencies.

Borehole Size

The hole size is not a critical parameter; larger borehole diameter slightly decreases the dominant frequency and may result in a lower signal to noise ratio. It causes, as well, reduction in the dispersion slowness values.

Formation anisotropy

In TI medium, when the axis of the well is parallel to the axis of the TI symmetry, the wave measures only the slower shear wave velocity. In deviated wells with more the 30º the first arrival falls in between fast and slow shear; above 60º deviation the wave clearly splits into fast and slow shear velocities. Field results showed that the splitting is observed only in formations exhibiting large anisotropy. Even though, the low amplitude of the event corresponding to the fast shear makes easier the contamination with drilling noise; the consequence is the dominance of the event that represents the slow shear velocity.

Tool azimuth effect

The quadrupole source is composed by four monopoles with alternating polarities. Tool azimuth is the angle between the two positive monopole-axis and x-axis. Experiments in slow TI formation with a tool rotated 45º about its axis demonstrated that waveforms are insensitive to the tool azimuth in wells deviated until 30º ; in high deviation angles (>60º) a significant delay is observed in the later arrivals.

Case Histories

The acquisition of shear slowness by wireline dipole and monopole and LWD quadrupole tools in the wells A, B and C allowed the comparison between the data.

Well A

Data were acquired by wireline and 8 1/4" LWD tool in a 12 1/4" borehole diameter drilled with 9.0/9.6 ppg OBM; the rate-of-penetration oscilated between 4-15 min/m. From the bottom to x730 m the formation is acoustically fast, composed by volcanic and tuffaceous rocks, carbonates, anhydrite, sandstones and shales; from x730m to the top, the formation is acoustically slow, composed by shales, marls and tuffaceous rocks.

Shear slowness values from monopole and dipole (wireline) and 8 kHz_quadrupole(LWD) fit very well in the interval x290/x110m. From x110m to the top, shear slowness values were obtained from dipole (wireline) and 8-4 kHz_quadrupole (LWD). With the exception of the intervals with fastest rocks (x947/x970m (carbonates), x690/x700m, x728/x740m (basalts) and monotonous sequences (x750/x850m (tuffaceous rocks)) where the values are similar, all the other intervals present differences up to 20% between both acquisitions with wireline slowness values, commonly, larger. In the interval x370/x660m the 8 Khz_quadrupole shear slowness maintains the value around 210 us/ft , close to the mud slowness value, being, probably contaminated (Fig. 4).

The three arm-caliper shows a slightly spiraling borehole below x660m; from x660m to the top, the caliper is irregular (Fig. 4- Track 1). Borehole diameter it's not the decisive factor for the differences because they are observed beyond the interval x370/x660m.

Image logs suggest that breakouts are associated with the shear slowness differences once they are absent in the interval x290/x140m, where all the shear slowness measurements fit very well, however this is not a rule of thumb. There are intervals above with same slowness values associated with breakouts (x738/x730m) and intervals with different slowness values that doesn't present breakouts (interval x837/x847m)

Wireline LQC logs show conspicuous correlogram and well defined first wave arrivals, even in the interval x370/x650m were the caliper is irregular. 8 kHz_quadrupole (LWD) presents clear first wave arrival and well defined correlogram from the bottom to x110m (interval where the 8_kHz_quadrupole dipole and monopole shear slowness fit very well). Above the formation signal is attenuated in the intervals. x110/x940m with strong tool arrivals from x940m to the top of the interval.

Services companies attribute the differences in shear slowness to the drilling damage exerted over the rocks. It would causes wireline shear slowness values larger than LWD values. In fact ,that's what is commonly observed, however, the interval x860/x880m shows the opposite.

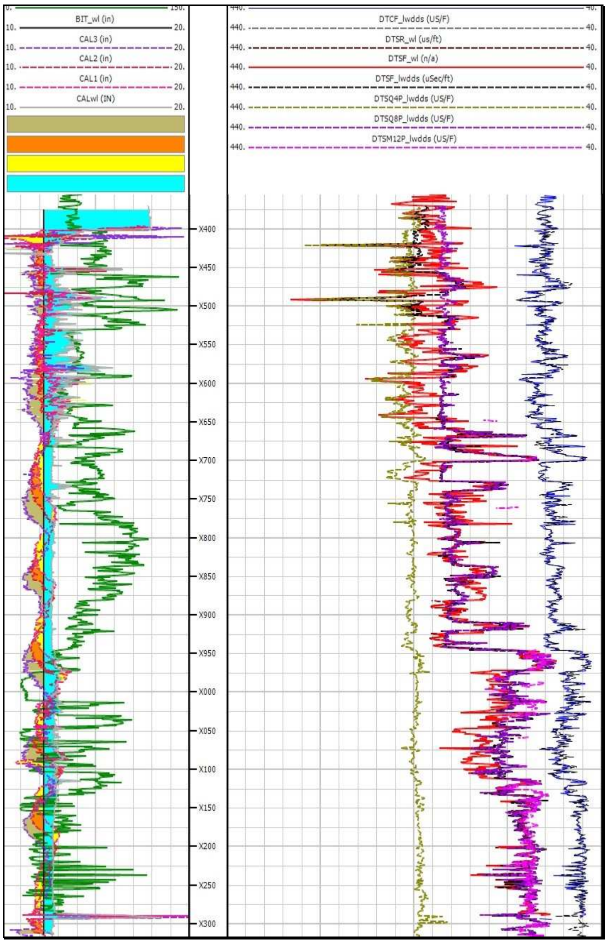

Fig. 4 – Well A shows 8kHz-quadrupole, dipole and monopole shear slowness fitting well from the bottom to x110m; above they hardly concide. On track 2 compressional and shear slowness curves. On track 1, caliper curves (C1,C2, C3 (three arm-caliper), CAL (one-arm caliper) and GR.

Well B

Data were acquired by wireline and 8 1/4" LWD tool in a 12 1/4" borehole diameter drilled with 11.4/12.5 ppg OBM; the rate-of-penetration oscilated between 4-20 min/m; caliper values are close to nominal values. Formation is acoustically fast, composed by shales and marls.

From the bottom to x020m the difference between monopole, dipole and 8 kHz quadrupole shear slowness values are acceptable (Fig. 5). The exceptions are the intervals x202/x173m (8 khz quadrupole lower values) and x075/x052m (dipole larger values and 8_khz_quadrupole smaller values). From x030m to the top, the 8 kHz quadrupole slowness values are continuously smaller than monopole values and dipole values are larger all over the interval; the average diference is 5% (Fig. 5).

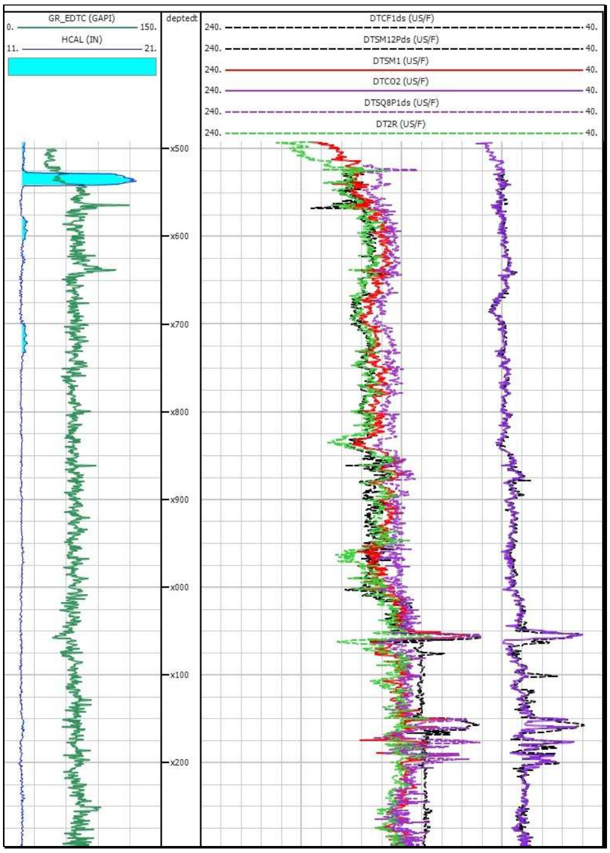

Fig. 5 – Quadrupole shear slowness (DTS) is the 8 kHz quadrupole value (violet – track 2).

The LQC log of 8 kHz shear slowness measurement shows good S/N ratio with high and unique coherence values in the interval.

The service company pointed out that different elastic rock properties caused the differences between the 3 modes in the superior interval. However, other logs (density, NMR) and rate of penetration suggest changes in depth of x150m.

If the changes considered are elastic, LWD and wireline compressional values would be sensitive to them, however they remain the same.

Well C

Data were acquired by wireline and 8 1/4" LWD tool in a 12 1/4" borehole diameter drilled with 9.5 ppg OBM; the average rate-of-penetration was 2 min/m; from TD to x750m, caliper values are close to nominal values, above some intervals reach 13"; . Formation is acoustically slow, fast only in thin intervals. It's composed by shales, marls and sandstones.

From x285m to x060m the 8 khz_quadrupole shear slowness values, varying around 210 us/ft, are strongly affected by mud slowness, alternating larger and smaller values with wireline shear slowness (Fig. 6). From x060m to the top the 4 kHz quadrupole shear slowness usually shows larger values than wireline shear slowness , excluding the interval x030m/x995m. Values fit acceptably until 240 us/ft, but the difference increases, reaching 12%, in higher values and where the caliper is out of bounds (Fig. 6).

LQC LWD log analysis shows a noisy acquisition in the interval where 8 kHz_quadrupole data was taken by the shear slowness (interval x300/x060m). The interval x183/x120m is very noisy; the interval x280/x183m shows values close to 210 us/ft, suggesting contamination with the mud slowness arrivals. The 4 kHz quadrupole LQC is slightly affected by tool modes and S/N ratio is acceptable with the first wave arrivals easily detected. Even though remarkably differences can be observed with wireline slowness values (Fig. 6). In the interval x030/x995m, the LQC log shows first wave arrivals not so noteworthy but high and unique coherence values; however the shear slowness values are significantly larger than wireline values and probably they are incorrect.

Services companies, in general, put the blame on the drilling effects over the borehole walls, once, in general, the differences shows wireline values larger the LWD values. The last example, nevertheless, indicates the opposite.

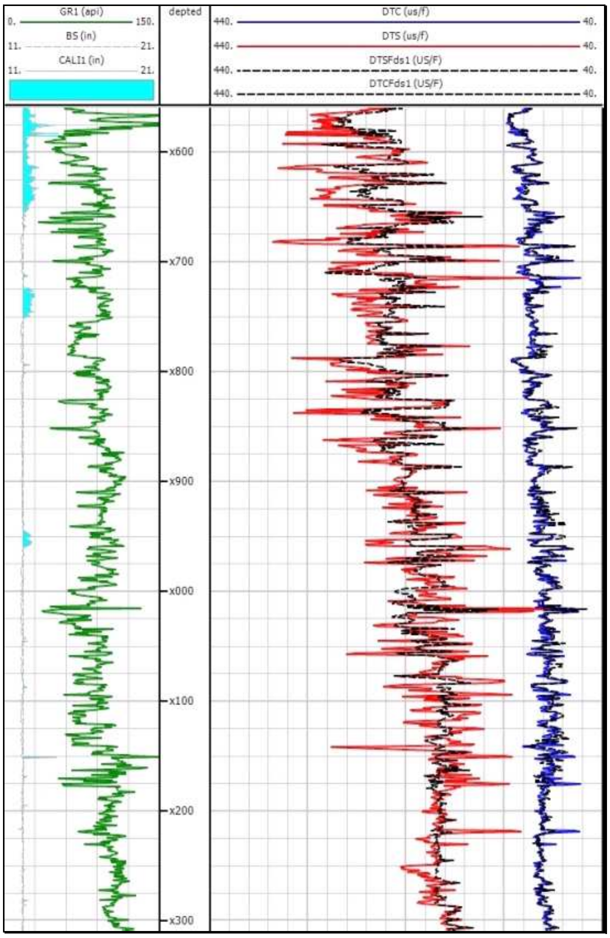

Fig. 6 – Shear slowness values (black – track 2) are taken from 8 kHz quadrupole measurement in the interval x305/x060m; from 4 kHz quadrupole measurement in the rest of the interval.

Conclusions and Recommendations

Dispersive waves generated by dipole and quadrupole sources require extra concern in the acquisition and processing; additionally the complexity of the LWD environment increases the responsability.

The examples had proven that in real situations, the shear slowness obtained from LWD quadrupole tools exhibit a high degree of uncertainty and its reliability is questionable. There are differences between wireline and LWD shear slowness values that can't only be explained by drilling effects (mechanical damage, invasion,…) over the borehole wall in slow and fast formations.

We recommend:

- Better background in acoustics for people involved in acquisition and processing of LWD quadrupole tool data.
- Quantitative investigation over the differences analyzed in this qualitative approach modeling data and situations, establishing degrees of uncentainties to the measurements involved.

Acknowledgements

We would like to thank PETROBRAS for permission to publish this paper. We're also in debt with Javier Omar Borri (Baker-Hughes) that processed the data and for his valuable contribution for technical discussions.

References

Kimball, C. V., 1998, Shear Slowness Measurements by Dispersive Processing of the Borehole Flexural Mode, Geophysics, **63**, 337-344.

Geerits,W.T., Tang, X.M., 2003, Centroid Phase Slowness as a Tool for Dispersion Correction of Dipole Acoustic Logging Data, Geophysics, **68**, 101-107

Schlumberger, 2011, Sonicscope – Multipole-While-Drilling Service , (Published internally for Petrobras),

Scheibner, D.,Yoneshima, S., Zhang, A., Izuhara, W., Wada, Y., Wu, P., 2010, Slow Formation Shear From an LWD Tool: Quadrupole Inversion with a Gulf of Mexico Example. paper T, 51ª SPWLA.

Tang, X.M., Dubinski, V., Wang, T., Bolshakov, A., Patterson, D. 2002, Shear Velocity Measurement in the Logging-While-Drilling Environment: Modeling and Field Evaluation, paper RR, 43ª SPWLA

Tang, X.M., Wang, T., Patterson, D. 2002, Multipole Acoustic Logging-While-Drilling, SEG Int'l Exposition and 72nd Annual Meeting.

Tang, X.M., Patterson, D., Dubinski,V., Harrison, C.W., Bolshakov, A., 2003, Logging-While-Drilling Shear and Compressional Measurements in Varying Environments, paper II, 44ª SPWLA

Wang, T., Tang, X.M., 2003, Investigation of LWD Quadrupole Shear Measurement in Real Environments, paper KK, 44ª SPWLA.