Well intervention system works the smart way

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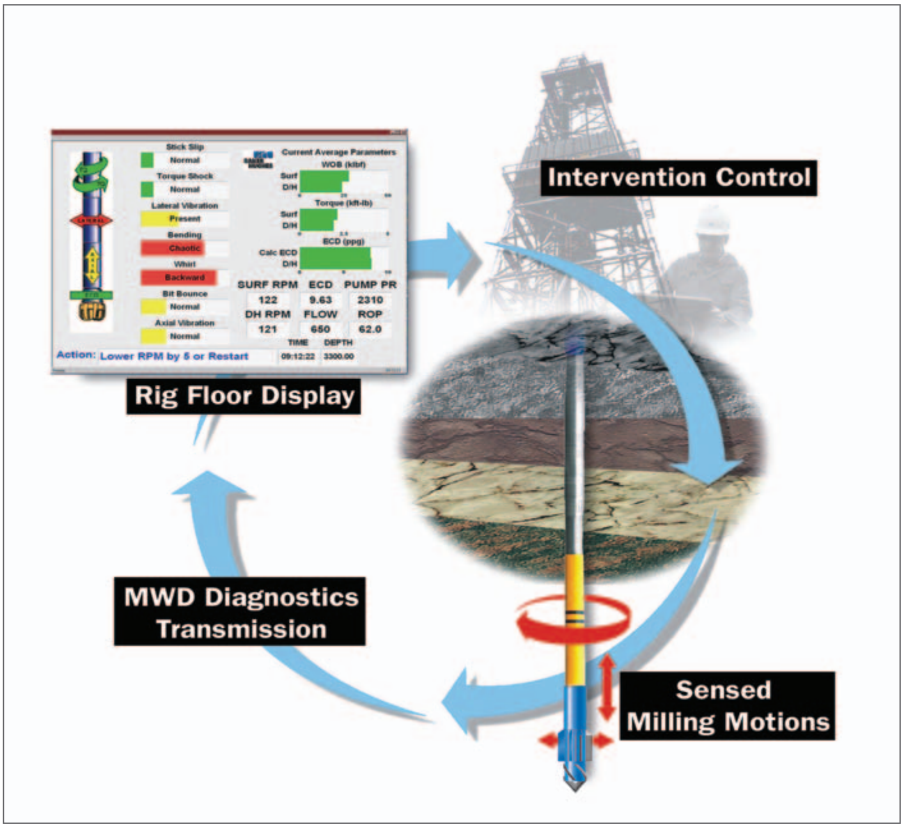

Baker Oil Tools' Smart Intervention system involves downhole data acquisition and processing in the Sentio sub; bi-directional data transmission to surface via MWD tools; and use of data for surface process control of intervention operations.

DOWNHOLE MEASUREMENT technology combined with real-time decision-making and the resulting closed-loop process control has optimized drilling operations and significantly reduced risk and cost. By working collaboratively, **Baker Oil Tools** and **Baker Hughes INTEQ** are incorporating the same technology and processes into fishing and milling, packer setting and recovery, casing exits for sidetracking and junction creation, and wellbore cleanup, to bring the performance and cost- and risk-reduction benefits of optimization to intervention operations.

In deepwater integration tests, Baker Oil Tools' new Smart Intervention system has proven its ability to provide operators with a new level of control that can lead to more efficient and reliable wellbore intervention jobs and to significantly reduce risk exposure. The enabling technology for the new system is three-fold: downhole data acquisition and processing in a smart intervention performance sub called Sentio; critical (bi-directional) data transmission to surface by established MWD tools; and utilization of data for surface process control of intervention operations.

Thus far, smart intervention has been used to observe vacuum filter operation in real time; quantify casing windows with a quality indicator; identify lightweight fish in real time at the bottom of deep, deviated wells; and accurately monitor packer setting forces and overpull in a variety of depths and deviations.

REDUCING RISK

Well intervention operations are specialized, often critical, and bring with them an inherent element of risk in the form of unseen subsurface conditions and events that can manifest themselves as unplanned non-productive time (NPT) with potentially severe fiscal consequences. Well intervention operations are traditionally performed using surface-acquired parameter measurements such as revolutions per minute (RPM) and hook load and complemented by a tool expert's sense of feel and anticipation. The industry is entering a period where this type of personal expertise is becoming scarce. Traditional surface-based indicators and gauges often provide inaccurate readings of the forces exerted at and around downhole tools. In applications such as milling, cutting, washing over and casing exit work, the lack of accurate information about downhole conditions often leads to wasted time and money. As wells become deeper, more tortuous and more technically challenging to intervene, the need to know more about what is occurring downhole becomes critical.

Historically, well intervention jobs have been managed as "open-loop" control systems that could be compared to firing an arrow from a bow. Disturbances to the flight process cannot be readily quantified, and when the arrow misses the target, the process starts again from the beginning, correcting only for the magnitude and direction of the miss but still unable to correct fully for any disturbance during the process. In extreme cases, the magnitude of deviance, particularly if the target is a long way off, can be so great that there is no way of knowing how far off the mark the arrow was until the target is retrieved. Similarly, with intervention jobs, milling for example, all the surface-acquired job information may indicate that the mill is performing an operation. Yet only after tripping out of hole can the mill be seen to be unworn, and the process must be repeated at considerable expense by tripping back into the hole for another attempt.

By using downhole rather than surface-acquired job information, the process can be monitored in real time. "Real time" in this context is a slight misnomer, as there is a transmission time delay. Thus, "pseudo-real-time" would be more technically accurate, but as the rate of change of parameters is fairly low in this application, discussing real-time process control in this application is valid.

- **Smart intervention performance sub**

The Sentio smart intervention performance sub contains an array of transducers and a digital signal processor (DSP). The transducers are strain gages, accelerometers, magnetometers and pressure and temperature sensors, some of which are placed in the x, y and z planes. All of these elements are analogue devices and output analogue electrical signals. All the transducers are sampled at a rate of 1 kHz and digitized by the DSP. From the digital signals, basic downhole parameters are available for output as static measurements; that is, as individual measurements of a condition at a point in time. These are axial tension and compression, recognizable as weight on mill, push on tool and tension, or pull on tool, torque, bending stress, RPM, axial, lateral, and torsional vibration, pressure, and temperature. Mathematical algorithms programmed into the DSP further process combinations of these static parameters into derived parameters of BHA whirl, mill bounce, stick-slip, vibration severity and differential pressure as equivalent circulating density (ECD).

• Bi-directional data transmission

All downhole parameters are sampled continuously at a high data rate, which gives rise to a substantial quantity of computed data. With limitless bandwidth, it may be possible to transmit all this data to surface. However, transmission bandwidth and data rate are limited currently to that which can be transmitted by existing MWD systems. Therefore, the data selected for transmission must be that which has the most value to the current operation. To that end, the system is programmed to prioritize the data stream elements in job-specific template formats and transmit the most critical information for the particular job type with greater frequency than data that is less critical or routine.

This scheme works effectively so long as the downhole variables remain constant. If downhole variance creates unforeseen subsurface conditions and events, the programmed data transmission sequence or data format may no longer be adequate. Programmed into the DSP are acceptance limits for all data streams. If one or more parameters go off limits, the DSP interrupts the programmed data format to transmit the deviant parameter value as an alarm to surface, and can even remain on the newly prioritized data format until the downhole issue is resolved.

Programmed or managed inadequately, the system could find itself in a constant state of alarm and reduce the volume or frequency of mission-critical data to an unacceptably low level, thus negating its "smartness." Fortunately, the system possesses bi-directional transmission ability, so if it receives sub-optimal parameter information, it can send signals from surface to the downhole tool to reset or reprogram the transmission data format to a more suitable one.

• Closing the loop

By bringing real-time downhole information into the fray, the opportunity arises for closed-loop process control. For example, as milling progresses, downhole job parameters are displayed at surface. The weight on mill, or even lack thereof, can be viewed with great accuracy and repeatability, with output value at surface corresponding accurately to the input value downhole. Other downhole parameters are also displayed, including torque; RPM; bending stress; axial, lateral and torsional vibration; pressure and temperature; BHA whirl; mill bounce; stick-slip; vibration severity; differential pressure; and ECD. Viewing these true downhole parameters at surface enables decision-making in real time.

This real-time decision-making is the function of the computer "brain" of the closed-loop process control. Any parameter that is sub-optimum will lead to a "system decision" to progress the operation more effectively and enact a surface parameter change that may range from changing weight on mill to removing untoward workstring dynamics and reducing cutting structure wear, or simply improving ROP. Changing a parameter at surface will have some type of effect on the mill downhole. Once that change takes place, the new parameter value will be transmitted to surface and displayed, starting an iterative closed-loop process that can continue until stability is achieved across all downhole parameters to allow a particular operation to approach, if not actually reach, its technical limit.

To date, a number of well intervention jobs have been performed in the deep wells and deep waters of the Gulf of Mexico using smart intervention technology. These jobs have included packer retrieval, fishing, milling, casing exits (sidetracks) and wellbore clean-out. A great deal has been learned about the performance of traditional tools and techniques, especially in deep, deviated wells. The most important learning, however, has been gained through the ability to actually observe what is happening at the working end of the BHA compared with what traditionally was thought to happen there.

WELLBORE CLEAN-OUT

A wellbore clean-out operation demonstrated the finer detail that could be observed with the system when surface operators noticed a debris chamber filling in very small weight increments, possibly as low as 2 lbs. The tool in question was a type of downhole vacuum cleaner called a Vectored Annulus Cleaning System (VACS), where the vectoring nozzles of a reverse circulating engine transfer conventional circulation to annular flow around a rotary shoe at the bottom of the BHA.

After wellbore debris is cut and stirred by the rotary shoe, the reversed flow continues back up the bore of the VACS, where debris is knocked out and retained in a cylindrical screen chamber. Debris-free fluid is then transferred from the tool bore to the annulus by more vectoring nozzles, where conventional flow is regained en route to surface. Using traditional methods, the quantity of debris captured by the screen could not be observed from surface. Neither could it be confirmed whether the reverse circulation was functioning correctly or operating in a stalled mode whereby the fluid bypassed the BHA and regained conventional circulation immediately upon exiting the vectoring flow nozzles.

Using the smart intervention system, the surface operators could clearly observe incremental BHA weight increases as the screen chamber filled with debris. By monitoring the increases, the operators inferred that the tool continued to operate effectively.

CASING WINDOW

The quantity and combination of performance diagnostics and static parameters produced by the smart intervention system come to the fore in casing exit operations. A number of casing exits have been performed with the smart intervention system, with many potentially mission-critical effects noted. Numerous effects have been observed that, left unchecked, would have had deleterious effect on the operation, particularly if the effects were allowed to continue in combination.

Torsional vibration during mill breakout, where the mill partially breaches the casing, was observed on a number of jobs. Left unchecked, this phenomenon can create a number of detrimental conditions. Severe torsional vibration, even for relatively short periods, can have a detrimental effect of the fatigue life of tool joints, particularly those of a window mill or follow-up mill. By definition, during torsional vibration, cutting elements cycle on and off load fairly rapidly. Left unchecked, the edge quality of the cutters will undoubtedly suffer, most likely by micro-spalling, which in turn will reduce the life of the mill to the point where it may fail to complete the designated operation in a single trip.

The cost of an additional round trip may compromise the economics of the operation. In one smart casing exit operation, the torsional vibration severity was displayed at surface in real time, which allowed the operator to make a real-time decision to instigate preventive action by increasing the downhole rotary speed to one at which the vibration dissipated and stability was regained.

Another detrimental condition that may not be observed at surface by traditional instrumentation is stick-slip, where the surface rotary speed appears constant but the displayed downhole conditions reveal otherwise. Left unchecked, this condition will substantially reduce the life of the mill's cutting efficiency to an uneconomic level. Fortunately, stick-slip can be eradicated by recognizing the condition at surface and varying operating parameters, such as circulation rate and RPM. Continued parameter update of downhole conditions then verifies that the situation is under control.

The ability to measure BHA bending stress downhole and see it at surface in real time is a major benefit to exit window creation. The ability to monitor BHA bending stresses across the window repeatedly in real time enables high-fidelity window profile, or quality, assessment, giving rise to the use of the smart intervention system as a window quality indicator. Because the assessment is made in real time with the window cutting assembly in the hole, any untoward anomalies in the window profile can be corrected immediately, assuring premium window quality and trajectory control at the technical limit. Problem-free insertion and retraction of future assemblies are ensured without further corrective trips. Combining the benefits of fatigue reduction, cutter life extension, window quality, and trajectory control elevates window creation to a new level.

DOWNHOLE LOADS

As 3-D and extended-reach well geometries become more common, the ability to ensure that downhole loads can be transferred to packer setting and removal equipment becomes critical.

Two applications have shown that overpull at surface is definitely not transferred downhole in all cases and does vary with drillstring design and well trajectory. Initial trials proved packer setting forces and overpull could be accurately monitored downhole at a variety of depths and deviations.

In one case, the surface overpull reached 100,000 lbs while downhole measurements showed roughly half of the tension reaching the BHA at 53,000 lbs. The limited weight transfer capability has direct implications for packer retrieval and downhole shear indications. The downhole information is vital to the decision-making process and enables confident real-time decision-making.

REPEATABLE MEASUREMENT

Packer retrieval operations, like many fishing jobs, often involve recovering small, lightweight components such as packer anchor latches, which weigh approximately 260 lbs. Recovering these components in deep, high-angle wells is typically fraught with difficulty due to high hole friction.

As in the operations above, it is not uncommon to have surface hook load indications vary by many tens of thousands of pounds. In such circumstances, when a successful latch occurs, the weight of the target component is invisible at surface. Using the smart intervention system, it has been possible to see on the surface display in real time that these lightweight fish were attached. Discontinuing latching attempts preserved the condition of polished seal bores and saved time, as the fish was immediately tripped out hole and the subsequent operation prepared with confidence while tripping out.

Using a remote real-time operations center adds another level of supervision to smart intervention operations and engages a much broader team of experts without impacting wellsite personnel requirements. To enhance the experience base, experts can be called on during critical wellsite operations and, in the process, improvement cycle for additional support, knowledge capture, lessons learned and process improvement opportunities.

THREE-PHASED APPROACH

Smart intervention is being introduced and developed at 3 levels: the real-time loop, the well-to-well loop and the engineering loop. In the real-time loop, an application is evaluated, goals and objectives are outlined, and an action plan is devised to meet them. The standard planning cycle is followed with all aspects of the project covered in peer reviews before the application is carried out. In the well-to-well loop, after-action reviews are conducted, and lessons learned are captured and disseminated. Performance guidelines can be modified and procedures updated based on lessons learned. The engineering loop is the culmination of the process improvement cycle and involves planning for optimizing the next smart intervention technology to further enable solutions that can be implemented in the cased-hole environment for a variety of downhole problems.

The 3-phased approach enables step-changes in efficiency and design improvements as part of a long-term strategy for continuous performance and process improvement and risk reduction.