Hammer time

Jack Kolle, Oil States Energy Services/ Tempress, USA, provides an overview of some extended reach well intervention tools.

The advent of extended-reach horizontal drilling and multistage hydraulic fracturing has led to a boom in onshore oil and gas production from shale reservoirs. The horizontal length of these wells and the number of frac stages has been steadily increasing. Today operators are drilling horizontal wells with a lateral length of 10 000 ft (Figure 1) with over 40 frac stages. The diameter of these completions is also increasing as operators focus on oil producing formations.

A typical horizontal well is completed with multiple hydraulic fracture stages. The frac stages are isolated using composite bridge plugs (CBP), ball-actuated frac sleeves or with a combination of the two. Coiled tubing (CT) deployed positive displacement motors (PDM) and mills are the favoured method of milling out ball seats and bridge plugs because of the speed of service and ability to maintain control of the well pressure as it begins to produce. Workover rigs offer a lower cost alternative to coil. This operation can be accomplished after the hydraulic fracturing is complete. CT is brought to location after the hydraulic fracturing is complete and the plugs and seats are milled out from all the wells on the pad in a continuous operation.

The ability to drill extended reach horizontal wells has outpaced the ability to re-enter the wells with coiled tubing or workover rigs. Drilling rigs have the ability to rotate the drill string, which keeps cuttings in suspension and reduces friction forces. Coiled tubing strings are smaller diameter and eventually experience helical buckling and lockup in extended reach wells. Smaller diameter workstrings and larger casings reduce the lateral reach at which lock-up occurs. Once the well is completed, the well intervention workstring must enter through the production tubing, further reducing the size.

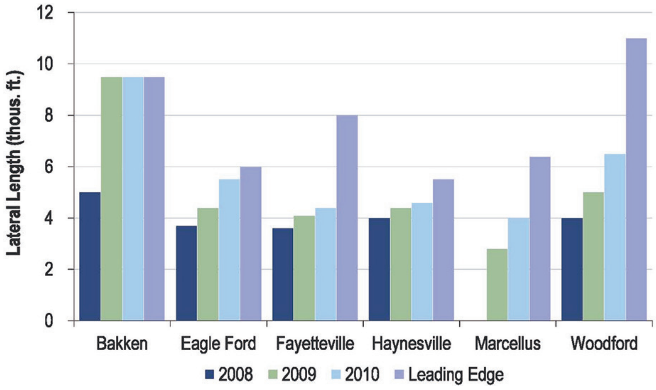

Figure 1. *The length of horizontal well completions is increasing. Source: KeyBanc Capital Markets Equity research.*

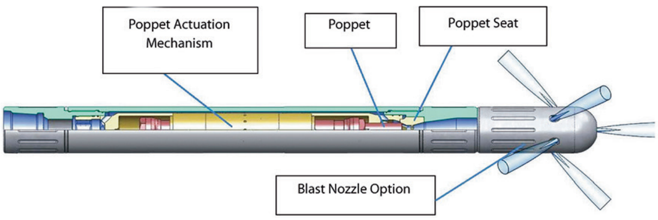

Figure 2. *HydroPull water-hammer tool equipped with a blast nozzle.*

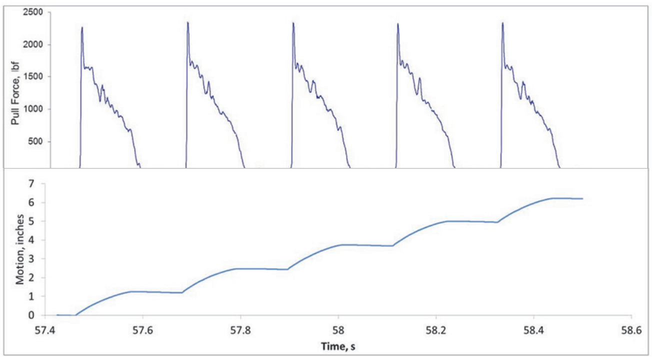

Figure 3. *HydroPull water hammer percussive impact force and motion of 2 in. coil (standard 2 ⁷⁄₈ in. tool at 2.8 bpm).*

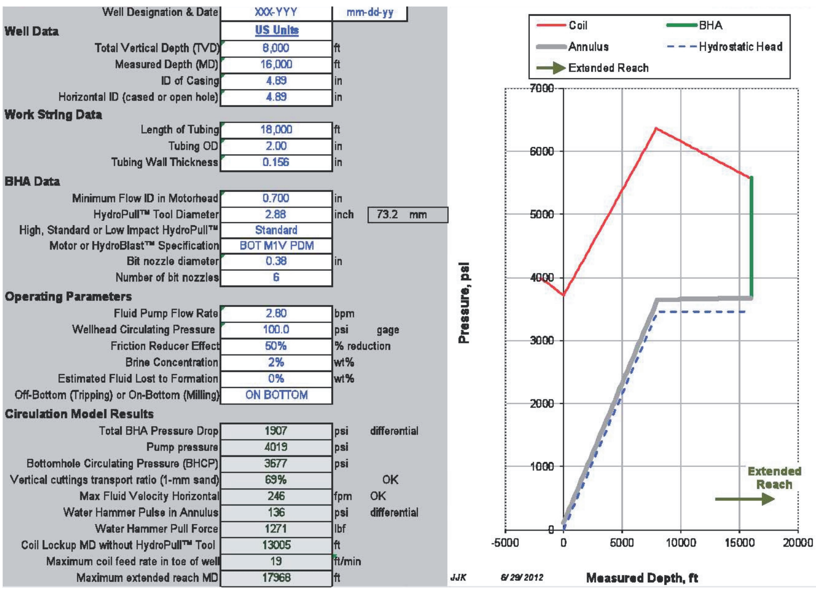

Figure 4. *HydroPull job planning software including CT circulation, cuttings transport and extended reach estimates.*

CT has a limited flow capacity, which limits its ability to remove frac sand and plug debris from the well. Depending on the reservoir, wells may have toe up configuration or a tortuous well path, which further complicates well entry.

In addition to the extended reach challenges, many wells may not have sufficient pressure to circulate completion fluids and cuttings out of the well. In some areas it is necessary to pump nitrogen to unload the well while milling plugs or performing sand cleanouts and other well intervention services. The nitrogen rate required to unload the well may exceed the flow capacity of the PDM.

Several through-tubing tools have been designed to address the challenges of extended reach milling and well intervention with CT or jointed workstrings.

The HydroPull™ water hammer is primarily used to extend the reach of the workstring by applying percussive water-hammer impacts to the bottomhole assembly. The impact forces pull the workstring further into the well than is possible by pushing on the coil and ensures effective weight transfer to motors and mills. The flow pulsations produced by the tool also enhance the transport of debris in horizontal wells and can be used to clean sand screens and gravel packs. The tools are also used for fishing operations in horizontal wells and as an alternative to actuating a jar to free a stuck workstring.

The motor gas separator MGS™ (Figure 6) bypasses gas above the motor to provide reliable circulation and motor operation when low pressures are encountered. These tools can be run in tandem with HydroPull water-hammers for extended reach intervention in low-pressure wells.

Both tools are high-temperature compatible to over 400 °F (200 °C). The HydroPull can be run on two phases, but a gas separator is recommended if a positive displacement motor (PDM) is run. These tools are available in sizes from 1 ¹¹⁄₁₆ in. for through tubing well interventions to 3 ½ in. for well completions. The most common size is 2 ⁷⁄₈ in. The operating principles, job planning and case histories of these tools are discussed here.

A new water-hammer design

Consider a typical milling operation with a motor operating at 2.8 bpm (0.007 m^3/s) on a deep string of 2 in. diameter CT. The coil may contain 10 t of water moving at 11 mph (5 m/s). The HydroPull water-hammer shown in Figure 2 incorporates a self-piloted poppet valve that stops most of this flow five times per second for around 0.1 sec., as shown in Figure 3. Stopping the flow at the valve stops and compresses the flow upstream for 150 m. The water acts as a 300 kg (660 lb) hammer. A 2 ⁷⁄₈ in. HydroPull with a standard configuration can generate percussive blow forces of 2000 lbf (900 daN) at a rate of 5 times per second at the bottomhole assembly (BHA). The high-impact configuration can generate 2700 lbf (1200 daN) percussive blows.

Hammers are useful tools

Tripping in

When tripping the BHA into the well, the percussive water-hammer force pulls and stretches the end of the tubing about 1 in. The speed of sound in steel is 7800 m/s, so a 0.060 sec. pulse stretches the bottom

470 m (1500 ft) of tubing. This stretch propagates as a stress wave up through the coil at the speed of sound until it reaches the CT reel on surface. Any given spot on the CT moves forward at 80 ft/min for 0.1 sec. then stops for 0.2 sec. and then moves again as illustrated in Figure 3. These stress waves cause the CT rig to shake, which is noticeable on surface even when the coil is deep in the toe of the well.

CT is subject to helical bucking and lockup due to friction forces when the length of coil in the horizontal section exceeds a critical value. Software is available that can be used to calculate the length at which coil will lock up inside of a straight section of horizontal casing. The software also estimates the additional reach that the water-hammer will enable. The model calculates the end force provided by the tool and assumes a 30% reduction in friction between the coil and casing due to the coil vibration. The model also calculates the rate at which the CT is pulled into the well by the water-hammer. Users can also calculate lockup depth with more comprehensive programs that account for well tortuosity. Once the conventional lockup depth is reached the CT feed rate should be reduced to match the recommended HydroPull feed rate, which is typically around 20 ft/min.

Substantial increases in lateral range are possible depending on the operating parameters. Although the water hammer force is smaller than the total friction forces on tubing in a long well, the tubing moves in waves that are only 1500 ft long. These waves dissipate slowly due to friction unless the well is highly tortuous. On 2 in. coil the range can be extended by over 5000 ft.

Milling

When the motor and mill encounter an obstruction, such as a bridge plug, the percussive impact forces are partially absorbed by the plug as it is milled out. Best practices for plug milling are to tag the plug and mill with minimum coil weight. As with a percussive hammer, the water-hammer provides the weight required to remove the plug. Plugs can be milled in a few minutes, but milling times of 10 - 15 min. are recommended to reduce the size of cuttings generated. The coil will feed in smoothly, and an experienced tool operator will rarely stall the motor. Fixed cutter milling bits or tricone bits can be used with equal success.

Short trips

Plug debris and considerable amounts of sand must be transported out of the well once a plug is milled through. Short trips accompanied by a polymer pill to help suspend cuttings are recommended after every six to ten plugs. The annular flow velocity while milling with 2.8 bpm of water in 5 ½ in. casing is only 130 ft/min, well below the 200 ft/min recommended for effective hole cleaning. The water-hammer also generates flow pulsations in the annulus, which when accompanied by vibration of the CT, helps to keep cuttings in suspension. Figure 5 shows how cuttings are transported in waves up the annulus. This flow pulsation reduces the average velocity required to cuttings transport to 100 ft/min.

The water-hammer percussion also vibrates the tubing, which reduces friction drag. The combination of these effects extends the lateral range of the tubing by delaying the onset of helical buckling and lockup. The tool is commonly run directly above a downhole motor for milling applications. The pressure pulsations improve weight transfer so that plug milling times in the toe of the well are the same as in the heel.

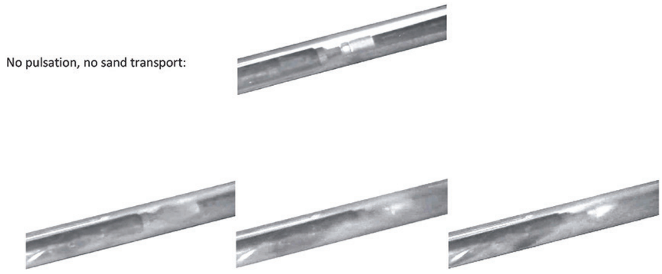

Figure 5. *Sequential stills from HydroPull sand transport video inside of a transparent test section at 100 fpm (0.5 m/s) average flow velocity.*

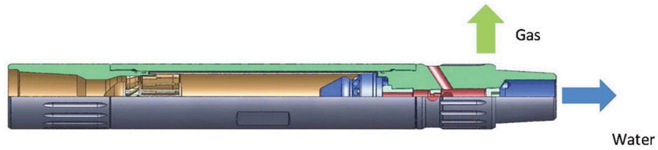

Figure 6. *Motor gas separator (MGS).*

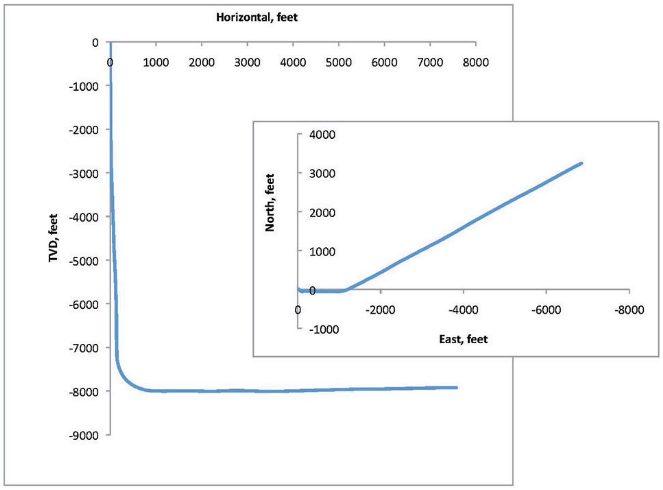

Figure 7. *Extreme reach CT sand cleanout well profile.*

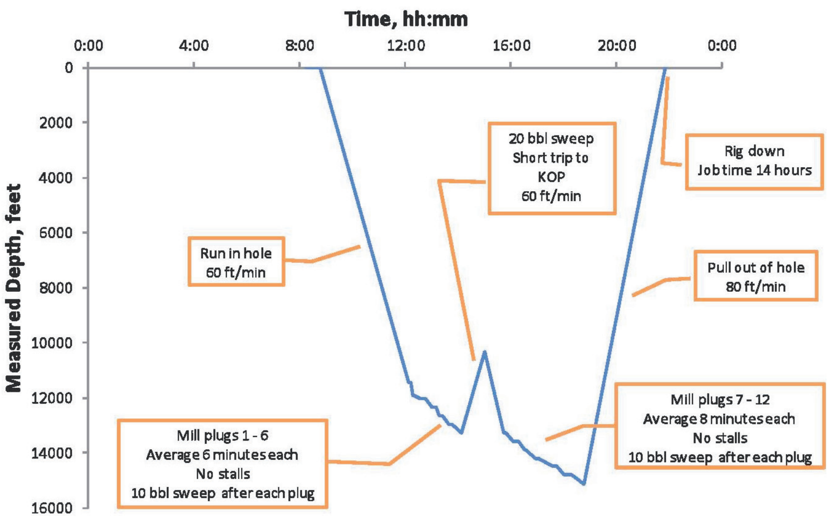

Figure 8. *Typical plug milling depth/time profile.*

Well stimulation

The same 2.8 bpm of water used for a typical well intervention inside of 5 ½ in. casing is moving back up the annulus between the coil and casing. The water is moving at an average speed of 130 fpm (0.7 m/s). Stopping this flow generates a suction pulse of up to 145 psi (1 MPa) over a 500 ft long section of the completion. This pressure causes the well to surge out of the formation, removing fines and debris from behind screens and completions. If the well is shut in, the flow surges into the formation. This is an effective means of dispersing solvents, scale treatment and surfactants into the formation near the wellbore.

Optimising motor flow rates

Nitrogen is often pumped along with water to ensure circulation of fluids and cuttings when a low-pressure zone is encountered. The MGS incorporates a turbine-driven, high-efficiency drum separator. Comingled nitrogen and water are separated inside the spinning drum. The gas exits though a crossover and is bypassed above the motor.

This tool is used to allow the use of optimum flow rates for the motor while bypassing any gas that may be used to lift the well. The tool incorporates a field-serviceable gas port that must be properly sized to accommodate the gas flow rate at downhole pressure and temperature. A two phase circulation model was developed in order to allow users to calculate these parameters and size the gas port for a given job. Alternatively, the operator may wish to change gas rates during the job and the model allows a calculation of the appropriate water rate to avoid overspeed while ensuring that the motor runs at full power throughout the job.

Case histories

To date, the primary application has been the milling of composite bridge plugs and frac sleeve ball seats. Other common applications are fishing operations, cement milling and shifting downhole sleeves.

Ball seat milling on jointed tubing

An independent oil and gas company operating in the Williston Basin needed to remove 40 frac seats from a multistage ball drop system. The frac sleeves started in a horizontal 4 ½ in. liner at 8885 ft (2708 m) and continued to a total measured depth of 18 075 ft (5509 m). A 2 ⁷/₈ in. BHA incorporating a HydroPull tool, Baker mud motor and 3 ¾ in. Baker Hughes Glyphalloy™ mill was used for this job. A total of 40 frac seats were milled in one trip with a total milling time of 10 hrs.

Extreme-reach CT sand cleanout

This job involved three wells that required sand cleanout in 5.5 in. (140 mm) casing at an extended reach of 6950, 7170 and 8009 ft (2118, 2185 and 2441 m). A 2.88 in. (73 mm) HydroBlast™ tool with a motor was run in these wells on 2 in. (51 mm) coil at 2.75 bpm (437 lpm). TD was reached on all three wells. A coiled tubing friction lockup model was run for each well trajectory. On the longest well trajectory, shown below, the model predicted coil lockup at a measured depth of 13 060 ft (3981 m), assuming a default value for the coil/casing wall friction coefficient. The HydroBlast tool enabled the coil to reach TD at 15 239 ft (4645 m), which is 3179 ft (969 m) beyond the predicted lockup point. On the 8009 ft (2441 m) lateral, this represents a minimum 52% increase in lateral reach. Although the average horizontal velocity in the casing was only 130 ft/min, all sand was removed from the wells.

Composite bridge plug milling

This typical job used a 2 ⁷/₈ in. (73 mm) HydroPull/ PDM in 5.5 in. (140 mm) casing. This was one of three jobs with an average plug milling time of 7 min. Only three stalls were observed out of 35 plugs milled total. A 10 bbl (1590 l) sweep was pumped after each plug was milled, and one short trip was completed after milling 6 plugs. The average time to complete each job was only 14 hrs.

Milling CBPs with a snubbing unit

This job in West Virginia involved milling 23 CBPs from 7150 to 13 814 ft using a stand-alone snubbing unit. A HydroPull tool was run with a Baker X-treme™ motor and 5-blade junk mill dressed with Glyphalloy. The job was completed in two days with an average plug milling time of 10 min. The water hammer allowed the use of a lower-cost snubbing unit with no rotary capability to complete this job.

Milling composite bridge plugs with two-phase flow

A 2 ⁷/₈ in. (73 mm) HydroPull tool was run with a motor and mill on 2 in. (51 mm) coil to mill bridge plugs inside 5.5 in. (140 mm) casing from 7500 to 13 000 ft (2286 to 3962 m) MD on four horizontal gas well completions (5500 ft/1676 m horizontal). For the first job, a MGS tool was run below the water hammer and above the motor. The tools were operated at 3.25 bpm (517 lpm) with 0.5 bpm (80 lpm) fluid, or gas equivalent, bypassed by the separator. Eight bridge plugs were milled in an average time of 8 min. each. In offset jobs running a competitive vibrating tool instead of the water hammer, the average milling time was 40 min. per plug.

For the next two wells, the gas separator was run above the water-hammer and motor to reduce the pulse amplitude. Each job involved milling 8 bridge plugs with fluid. The average milling time per plug was 15 min.

On the last well, nitrogen was run to maintain circulation while drilling the last two bridge plugs. Nitrogen dampened the pulse amplitude but did not reduce the milling speed.

Cement milling

A major operator on the North Slope of Alaska was experiencing unwanted gas production in the heel of a well that was recently sidetracked. The challenge was shutting off the gas producing perforations above, while preserving a 100 ft section of perforations at the toe of the well. The solution was to isolate the toe and squeeze the gas producing perforations, and then mill the plug allowing production from the toe. After drifting the wellbore, a CBP was set approximately 180 ft above the perforations at the toe of the well, at 11 420 ft MD. A gel and cement treatment was pumped to shut off the gas producing perforations. All facets of the plug and cementing operations went as planned; however, when milling operations ensued following the cement squeeze there were noticeable weight transfer issues while attempting to mill cement with just the 1 ¹¹/₁₆ in X-treme motor.

The water-hammer was picked up along with a milling BHA consisting of an HCC Diamond Parabolic mill (1.75 in. OD), BHI X-treme motor, circ sub, disconnect, jars, back pressure valve, dimple-on coil tubing connector and 1.5 in. OD coil tubing. Once on bottom milling, the remaining 220 ft of cement was milled up, as well as the CBP. Although a number of stalls were encountered during the operation, consistent weight on bit was achieved throughout the milling process. OT