be determined by comparing stand pipe pressure between shifts of the tool. A noticeable psi difference in SPP will be seen when shifting between flow to the bit and flow to the annulus (**Figure DH-3**). The amount of pressure differential seen depends on the size of the tool and restrictions in the BHA below. Temperature will not affect the maximum flow rate of the tool since a steel ball and seat are used.

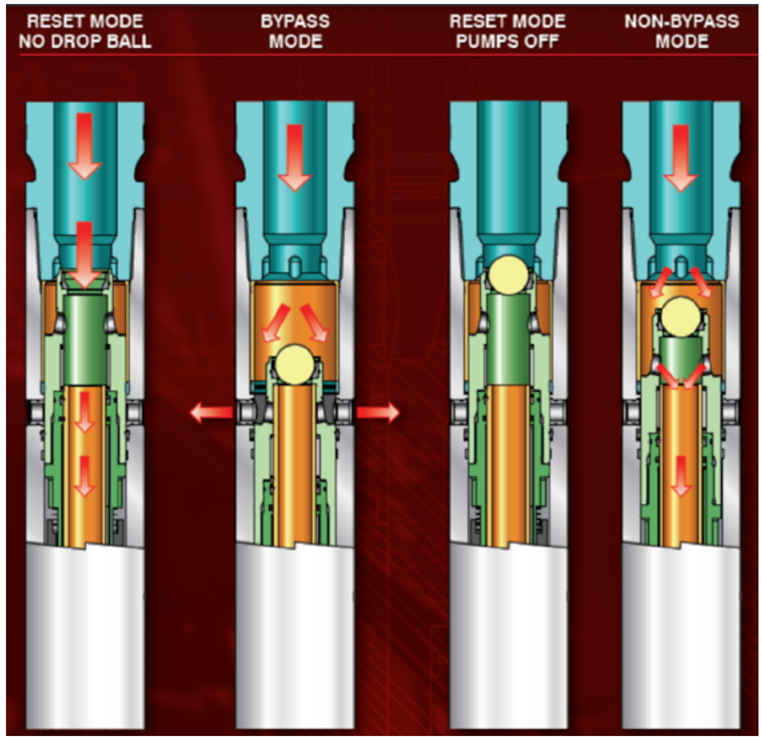

Figure DH-3: The 4 possible conditions in a multi-opening circulating sub. Courtesy National Oilwell Varco.

Applications

LCM Placement

The most common application for circulating subs today is placing aggressive LCM pills in lost circulation zones in the formation. Due to LCM's nature to plug holes in the formation it is inherently hard to pass through BHA components with small through bores or passages, such as bits, downhole motors and MWD tools. Circulating subs are typically placed above these components and allow the use of aggressive LCM pills that would generally clog up these BHA components. Circulating sub ports have large annular port diameters that are much harder to clog than bit jets or MWD bores. Once the circulation sub is activated, fluid only passes through these large OD ports and on to the annulus, thus bypassing the more sensitive BHA below. It is not uncommon to need to bypass the BHA multiple times during a single run due to lost circulation. For this reason, circulation subs with the ability to shift from bypass (flow to annulus only) to non-bypass (flow to the bit) are often used.

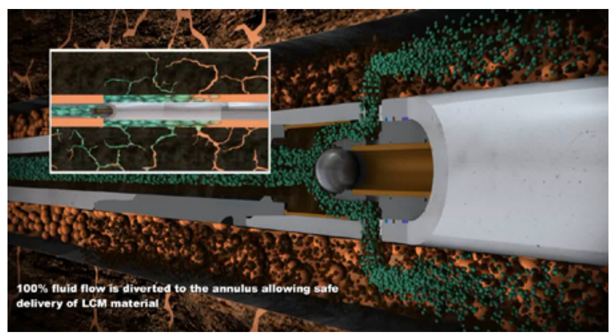

Figure DH-4: Multi-opening circulating sub tool in lost circulation application.

Wellbore cleanout

In wellbore cleanout applications, whether while drilling or during completion phases of the well, the tool permits an increased circulation rate to be applied by opening flow paths to the annulus of the well above the flow-restricting components of the BHA. Bypassing the BHA allows the maximum amount of fluid to be forced through the circulating sub OD ports to the annulus, thus increasing the total flow area and lowering the stand pipe pressure. In most cases, this is done while rotating the drill string to provide an evenly distributed 360 degree turbulence path where fluid is entering the annulus. 'Bottoms-up' circulating time is greatly reduced and hole cleaning is improved by bypassing flow to the annulus.

Deviated drilling

In deviated wells and especially in extended-reach laterals, the increased fluid velocity and turbulence aid in lifting cuttings up off the low side of the wellbore and homogenizing the distribution of cuttings within the drilling fluid. As velocity and turbulence decrease, farther away from the flow at the bit, gravity is more likely to act on cuttings and debris and cause it to fall to the low side of the wellbore. As cuttings build up on the low side of the drill string and around its sides, the contact area on which the string rests increases, increasing the frictional forces between the drill string and the wellbore. This of course causes increases in overall torque while decreasing the ability to effectively transfer weight to the bit. The end result is a drilling condition that raises the potential for stick slip, vibration, and stuck pipe events. Proper annular velocity and turbulence is required to suspend the cuttings in the fluid and make them available for transport up the annulus and back to surface. In wells such as these, where mud motors, MWDS, and other flow restricting components are present, it is often difficult to achieve flow rates high enough to generate turbulence and annular velocity high enough to effectively transport cut-

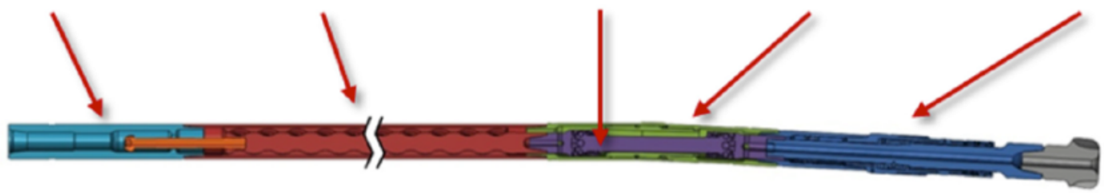

Figure DH-5: Components of a downhole mud motor.

tings without over spinning the motor. In some cases, flow rates above a mud motors maximum flow rate are needed to clean the hole. By bypassing the motor and preventing overrun, a circulating sub can increase the motor's reliability and operating hours. This reduces wear on the motor and reduces the chance of damage caused by high rpm seen when excessive flow rates are used to clean the hole.

Safety and handling

Circulating subs are picked up and installed in the drillstring like most other smaller drillstring components. In most cases tongs should only be placed at the top and bottom of the sub for the purpose of torqueing and un-torqueing the connections. Tongs should not be placed around the area where the ports are located. Regular pipe dope is to be used.

Care should be taken when dropping balls and/or darts down the drill-pipe to (de)-activate the subs.

General maintenance

Maintenance of the subs are mostly performed at the site of the supplier of the technology being used, however the threads that make up the connections should be maintained by applying proper pipe-dope and protected with the correct thread protectors.

Downhole mud motors

These are also referred to as mud motors, positive displacement motors (PDM), Moineau motors, performance motors, and progressive cavity pumps. See the separate chapter on Directional Drilling in the IADC Drilling Manual, 12th edition, for more information. **Figure DH-5** diagrams the main components of a downhole mud motor.

Top sub (saver sub)

The top sub is simply a cross-over housing at the top end of the motor used to ensure proper connection type and to extend the usable life of the stator (**Figure DH-6**). The top connection is typically an API tool joint box, and is available with an optional "float bore" to accommodate API float valves. The lower connection usually uses a proprietary thread depending on the manufacturer that connects to the upper box of the stator housing.

Dump sub

The dump sub allows fluid to bypass the motor and fill the bore of the drill string when tripping into the hole. It also allows the drill string to drain when tripping out of the hole. When no dump sub is used, a wet trip out of the hole will occur if no other means of drainage is employed. There is little pressure loss through the dump sub when operating.

The dump sub is also referred to as the bypass valve, dump valve and bypass sub.

Rotor catch assembly

Extreme torque is generated at and near the power section and the joint connections are the weakest points in the string. For this reason some manufacturers include a rotor catch system that maintains a connection to the BHA even

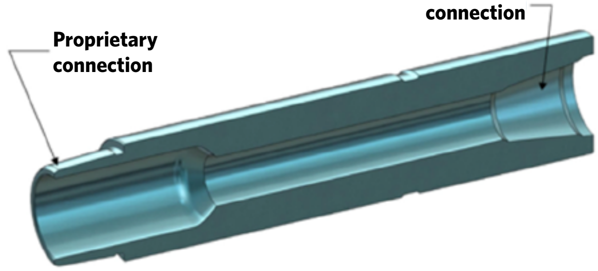

Figure DH-6: Top sub of a downhole mud motor.

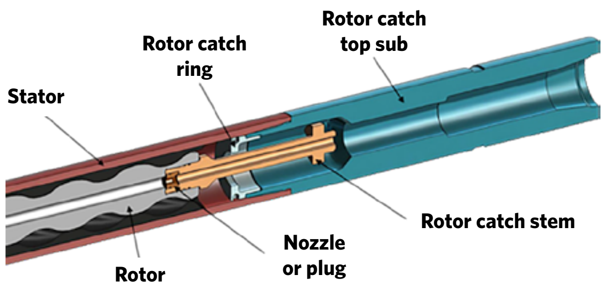

Figure DH-7: Rotor catch assembly.

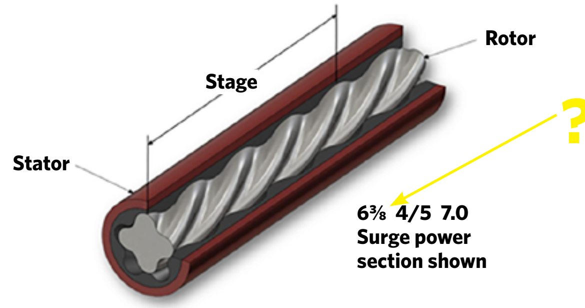

Figure DH-9: Stage power section.

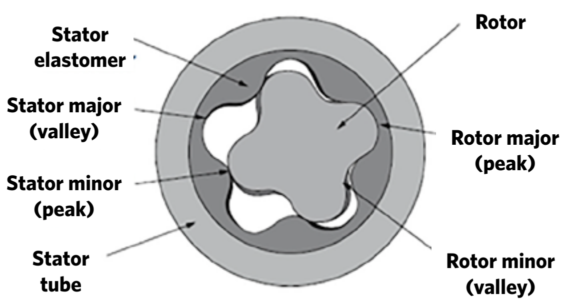

Figure DH-8: Rotor and stator cross section.

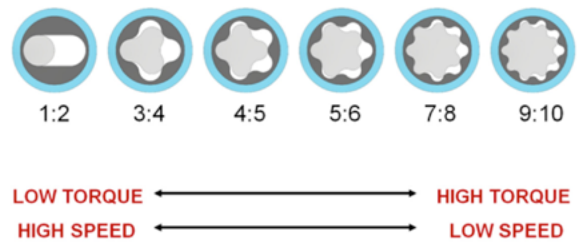

Figure DH-10: Common lobe configurations with a generic summation of performance.

if the connection between the power section and top sub breaks. This is a back-up mechanism to help prevent significant loss of equipment if the BHA were to break off at this point.

Power section

Power sections are the portion of the motor which transfer the axial force of mud flow into torsional force for transmission to the bit. The primary components are the rotor and stator (**Figure DH-8**). The rotor is a long helical steel component that sits inside the stator. The stator is a long tubular component with elastomer lining.

The two parts fit together with a complimentary helical geometry that allows the conversion of axial force to torsional force. The rotor and stator are designed as helical elements with a major and minor diameter. The stator will have one more lobe than the rotor. The lobe is the curved spiral shape formed by the difference in the major and minor dimension. This difference in lobe count creates a fluid inlet area (cavity) where fluid can be pumped through to create rotation.

Transmission of axial to torsional force

- The surface pump pressure forces mud into the power section inlet
- The first cavity at the top takes the mud in
- As this fluid cavity moves down through the stator, it pushes against the rotor, creating rotation
- The cavity moves down through the stator, emptying out the bottom end
- Pressure continues to fill the spiral cavities and they continue rotating to empty
- Each cavity is a fixed (constant) volume, so the higher the flow rate, the faster the rotor turns

A stage is the distance measured parallel to the axis between two corresponding points of the same spiral lobe (**Figure DH-9**). This distance is commonly referred to as the lead of the stator.

A power section's design is identified by its outer tube diameter, rotor/stator lobe configuration and number of stages. Tube sizes range in general from 1 ¹¹⁄₁₆-in. to 11 ¼-in. tube OD. The lobe configuration selection is dependent on the application need. As a general rule, a high rotational speed power section will produce lower torque; inversely a low speed power section generates higher torque. **Figure DH-10** shows common lobe configurations with a generic summation of performance:

The rotational speed generated by the power section is proportional to the rate of fluid flow through the power section, i.e. increasing the flow rate through a given power section directly increases the output speed. To increase the output speed of a power section without changing the flow rate, the cavity size is changed. A high speed power section will

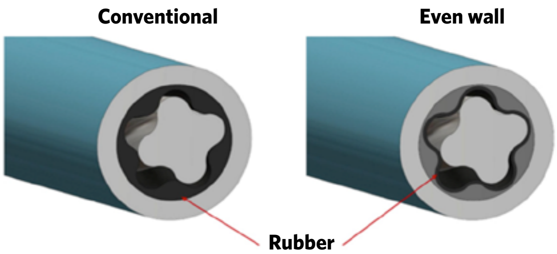

Figure DH-11: Conventional vs even-wall power section. Courtesy National Oilwell Varco.

Figure DH-12: The adjustable assembly connects the stator to the sealed bearing assembly and encloses the driveshaft assembly. Courtesy National Oilwell Varco.

require a larger fluid inlet area (cavity) to allow more fluid throughput into the cavity.

The torque generated by the power section is proportional to the differential pressure applied across the power section and is independent of fluid flow. Generally, the more weight applied to the bit, the higher the torque needed to keep thebit turning, so the higher the differential pressure across the power section.

The maximum recommended differential pressure is limited by the stator elastomer. If pressure increases beyond the limits of the elastomer, the stator elastomer will deform, breaking the cavity seal so the mud flow leaks past the rotor and rotation stops – this is commonly known as a stalled motor.

An increase in torque output can be achieved by three methods:

- Use a power section with more stages. As torque is proportional to the applied differential pressure, a power section of similar tube diameter, lobe configuration and profile construction will generate more torque as the number of stages increases;
- Use a high performance elastomer. Specially designed elastomers can allow as much as 50% higher differential pressure across each stage, generating 50% more torque with the increase in differential pressure;
- Use an even wall power section (**Figure DH-11**).

Even wall power sections have a contoured stator tube ID and a thin elastomeric liner of even thickness. Backed by the contoured tube, the thinner elastomer liner maintains its sealing ability up to 75% higher differential pressure across each stage.

Adjustable assembly and fixed housings

Adjustable assembly

An adjustable assembly (**Figure DH-12**) connects the stator to the sealed bearing assembly and encloses the driveshaft assembly. The angle setting is field adjustable to produce a wide range of build rates.

Fixed housing

Fixed, non-adjustable housings are available (special order) in straight or fixed bend configurations.

Driveshaft assembly

The driveshaft assembly converts the eccentric motion of the rotor into concentric rotation for the bearing assembly. It also accommodates any angle set on the adjustable bent housing (or fixed bend housing) and carries the thrust load from the rotor caused by the pressure drop across the power section. The assembly consists of a driveshaft and two sealed and lubricated universal joints connecting to the rotor and the sealed bearing assembly.

Bearing Assembly

» *Oil sealed bearing assembly*

The bearing assembly transmits the rotation of the driveshaft assembly to the drill bit. It transmits the compressive thrust load created by the weight of the collars and drill string to the rotating bit box, and supports the radial and bending loads developed while directional or steerable drilling. It also carries the tensile "off-bottom" thrust load produced by the pressure drops across the rotor and the drill bit, as well as any load caused during back reaming. In oil-sealed bearing assemblies the radial bearings and thrust bearings are lubricated by and sealed in an oil chamber balanced to the internal tool pressure (**Figure DH-13**).

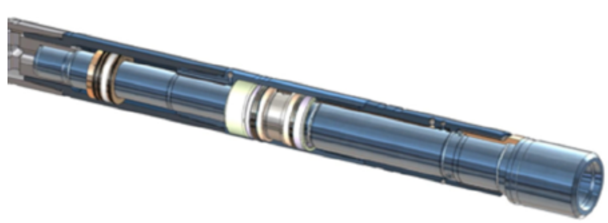

Figure DH-13: Oil sealed bearing assembly. Courtesy National Oilwell Varco.

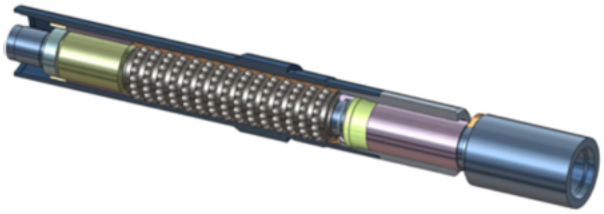

Figure DH-14: Mud-lubricated bearing assembly. Courtesy National Oilwell Varco.

» *Mud lubricated bearing assembly*

The mud lubricated bearing assembly is interchangeable with the sealed bearing assembly and performs the same basic function (**Figure DH-14**). In a mud lubricated assembly, a small percentage of the drilling mud is allowed to pass through the bearing chamber, to lubricate the bearings. Mud lubricated bearing assemblies can be used in the hottest holes with the lowest aniline point drilling fluids, as there are no elastomeric seals.

Applications

Directional drilling

Most motors are used with adjustable housings to provide a method of drilling directionally downhole. The desired angle is obtained by selecting an appropriate fixed bend housing or is set in the adjustable housing sufficient to alter hole course with the drillstring not rotating and the tool face oriented. When the drill string is rotated with the motor operating, the system drills straight ahead.

» *Run preparation & rig site testing*

- Set the motor in the slips and install a safety clamp. Remove the lift sub and make up the Kelly/top drive. Remove the safety clamp and slips and lower the motor until the dump sub is below the drilling nipple, but visible.
- Start the rig pumps slowly; fluid should flow out of the dump sub ports.
- Increase the pump rate slowly until the dump sub closes. Leave the pumps running and make note of the circulation rate and stand pipe pressure when the dump sub closes. With the pump running and the dump sub closed, check to ensure that there is no drill fluid leakage through the ports. It is advisable to increase the pump speed in two or three steps, to the maximum circulation rate expected downhole, and note the circulation rate and standpipe pressure in each case.
- Shut down the pump. The dump sub may not open due to a pressure lock in the short hydraulic test circuit. If this occurs, bleed off the pressure to permit the dump sub to open.
- Make up the drill bit to the proper torque with a bit breaker and the rig tong placed on the output shaft directly above the bit. Do not put rig tongs on the sealed bearing assembly housings. Inspect the output shaft seal area for any indication of an oil leak.

Note: Avoid long periods without circulation if possible.

» *Starting the motor*

Begin circulating "off bottom" with the bit turning freely. Perform circulation and pressure tests at the same circulation rates as the surface test, and note the readings. The pressure will be higher due to the restrictions of the drill string components added. The "off bottom" pressures noted may be higher than calculated. This is caused by bit dragon the side of the hole due to the bent sub, adjustable housing angle, and stabilization.

» *Drilling*

After a short hole-cleaning circulation period, slowly lower the bit to bottom. When bottom is tagged, the standpipe pressure gauge will show an immediate increase. Increase the bit weight slowly to achieve the desired build up rate and/or rate of penetration. Do not exceed the recommended maximum differential pressure across the motor.

The "off bottom" pressure is the total system pressure (read on the stand pipe gauge), from the standpipe, through the drillstring, the annulus, and back to the drilling nipple, while circulating with the bit "off bottom" (i.e., zero weight on bit). Periodically recheck the "off bottom" pressure. The standpipe pressure will slowly increase after hole cleaning due to the hydraulic energy required to lift the cuttings.

The torque applied to the bit while "on bottom" is directly proportional to the difference between the "on bottom" and "off bottom" pressures (i.e. there are no friction losses through the rotating drillstring). An increase in the weight on bit produces an increase in torque. As the bit drills off, the weight on bit decreases and correspondingly the pressure and torque decrease. The standpipe pressure gauge can therefore be used as a torque indicator.

» *Stalling*

If too much WOB is applied, the torque required to keep the bit turning creates a higher differential pressure than the seal between the rotor and stator elastomer can maintain. The drilling fluid breaks the seal and leaks through the power section without turning the rotor, so bit ceases rotation, or 'stalls'. An increase in standpipe pressure will occur and penetration will cease. As the fluid leaks past, it erodes the elastomeric liner, which makes further stalling more likely and damages the liner, eventually leading to chunking.

