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State of the Art Positive Displacement Motors Enhance Vertical Drilling Performance.

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Abstract

Positive Displacement Motors have widespread use in vertical drilling in many areas. Benefits are seen in enhancing penetration rates and minimizing drill string wear.

This paper looks at how advances in motor power section design have allowed enhanced drilling performance across a wide range of drilling applications.

New generation low speed high torque motors have been used to optimize PDC bit performance in hard rock drilling as well as extending roller cone bit life to new limits.

Purpose designed high-speed motors have added a new dimension to drilling with diamond impregnated bits providing an economic alternative to the use of turbines.

Proper sizing of the motor power section for the downhole conditions will insure motor durability with run length being of equal importance to penetration rate under harsh drilling conditions.

Introduction

The positive displacement mud motor is the workhorse of directional drilling operations throughout the world. Originally used with single shot survey tools and bent subs for orientation the motors were run specifically to kick the well off from vertical, sidetrack or make correction runs. Single shot orientation was done off bottom and the reactive torque of the motor had to be taken into account through experience and interpretation of survey data. High-speed low torque motors were used to minimize reactive torque. Motors were kept as short as practical to insure the bent sub would be close enough to provide the doglegs required.

By the 1980s MWD tools allowed monitoring of the motor orientation while drilling. This in turn enabled the use of motors with greater torque output through the mulitlobe power section and by the end of that decade the steerable mud motor was becoming commonplace. Once the bend in the motor had been placed below the power-section it was possible to increase the length of motor above and a new generation of extended power motors evolved.

Today advances in rotor and stator manufacturing capability have allowed the production of higher torque motors across a wide range of bit speeds. Matching the motor output torque and RPM to the requirements of bit and formation has led to significant increases in penetration rates over the complete spectrum of drilling conditions.

Vertical drilling with a motor is a common practice in many areas. Not only do the motors increase penetration rates but help maintain verticality and minimize drill string wear. The latest generation of motors has been able to make a particular impact on drilling performance in hotter and tougher drilling conditions.

The Positive Displacement Motor

In a positive displacement motor the power section converts hydraulic energy from the drilling fluid into mechanical power to turn the bit. This is accomplished by reverse application of the Moineau pump principle. Drilling fluid is pumped into the motor's power section at a pressure that causes the rotor to rotate within the stator. This rotational force is then transmitted through a transmission shaft and drive shaft to the bit. The rotor is manufactured of corrosion-resistant stainless steel and is chrome plated to reduce friction and abrasion.

The stator consists of a steel tube with an elastomer (rubber) lining molded into the bore. The rotor and stator have similar helical profiles, but the rotor has one less spiral, or lobe, than the stator In an assembled power section, the rotor and stator form a continuous seal at their contact points along a straight line, which produces a number of independent cavities. As is forced through these progressive cavities, it causes the rotor to ratchet around inside the stator

The power section of a downhole motor is designated by its rotor/stator lobe configuration and its number of stages. For example, a 4:5 power section has four lobes in the rotor and five in the stator. Generally, the higher the number of lobes, the higher the torque output of the motor and the slower the speed. The lobes on a rotor and stator act like a gearbox. As their numbers increase for a given motor size, the motor's torque output generally increases and its output shaft speed generally decreases. Because power is defined as speed times torque, a greater number of lobes in a motor does not necessarily produce more horsepower.

Increasing the number of stages in a motor will increase the available torque output. The stator stage length is defined as the axial length required for one lobe in the stator to rotate 360° along its helical path around the body of the stator. The stage length of a rotor, however, is not equivalent to the stage length of its corresponding stator. A rotor has a shorter stage length than its corresponding stator.

Stage length is dependent on the lobe pitch angle of the spiral. As the pitch angle increases, resulting in a tighter spiral and shorter stage length, the force vector perpendicular to the longitudinal axis of the rotor (torque) and the volume of the cavity within the stage decrease. This results in a reduction of torque output and an increase in the motor’s speed. Conversely, a decrease in pitch angle produces a longer stage length, resulting in an increase in torque and a decrease in speed.

New Generation Motors

Schlumberger's GT line of PowerPak motors has been designed to match the speed and torque requirements of today's bits. The maximum output torque is achieved for the desired RPM range for each motor. The first of the GT motors was the 4 3/4" or A475GT. Fig-1 illustrates the evolution of motors in that size from the original SP through the XP to the GT. In the picture the motors are fitted with sealed bearing assemblies and are 18 feet, 24 feet and 28 feet long respectively. Maximum horsepower is 54HP, 93HP and 130HP.

At the top end of the range in terms of size is the A962GT. This 9 5/8 OD motor with a 7:8 lobe configuration was designed for harder rock drilling in 12 1/4" hole. With 18,000-ft lb. of torque available at low speed the motor is ideally suited for performance drilling in higher compressive strength formations.

Where formation strength demands the use of a diamond-impregnated drill bit the HS series of motors provides an alternative to turbine drilling. These 2:3 power sections provide a combination of bit speed and torque which allows faster drilling at higher bit weights than are possible with a turbodrill.

Fig-2 illustrates the range of torque and RPM output for the GT motor series at for three hole sizes at a given flow rate.

Durability

Drilling economics are not only a function of ROP but of bit run length. The durability of the bit and motor are equally as important as penetration rate for performance drilling success in harder rock.

Preparing a motor for each job requires assembling the motor under quite different conditions to those that are experienced downhole. For optimum performance it is critical that the rotor and stator are fitted for the expected drilling conditions taking into account temperature, pressure and drilling fluid. The difference between the size of the rotor mean diameter and the stator minor diameter is defined as the rotor/stator interference fit.

Empirical testing of stator elastomers with a wide range of drilling fluids allows prediction of their behavior under a range of temperature and pressure conditions. The elastomer may swell through increased temperature or chemical reaction with the mud while the degree of swelling will also depend on hydrostatic pressure of the drilling fluid. PowerFit is a proprietary application program, which is used to predict the amount of swelling to be expected for each motor at the anticipated drilling conditions. Accordingly the rotor and stator can be sized on surface to provide the correct downhole interference fit.

An incorrectly sized power section will likely result in a premature end to the bit run. If the motor swells too tight, frictional forces will cause the core of the stator lobes to overheat and harden. Subsequently the outer rubber will tear off in strips and the motor will fail. If the motor is set up too loose it will not generate sufficient power and will be liable to stall. During a motor stall the rotor stator seal is broken resulting in extremely high fluid velocities across the interface. Regular stalling will weaken the elastomer and again result in motor failure.

Use of the PowerFit software has enabled major advances in high temperature performance with 200-hour runs now being achieved in oil based mud at 300degrees F.

Bit and Motor Synergies

Fig-3 illustrates the relationship between formation compressive strength, penetration rate and bit type. Obviously there is a considerable amount of overlap and bit selection will also take into account formation abrasiveness, hydraulic conditions and the required run length. Bit performance in terms of ROP and durability will depend on the drilling parameters used. As such it is important that when a motor is to be used it will operate with the required weight on bit, RPM, flow rate and hydraulics. Taking a system approach to bit and motor selection can have many advantages. Viewing the bit and motor as a drilling system allows optimization of bit nozzle selection. The bit requirements must be taken into account while insuring the motor will deliver the required horsepower and the hole can be cleaned. Post run wear analysis of both bit and motor can be compared to get a better view of downhole conditions with a view to fine tuning system selection.

Flow Rate

The bit speed generated by a motor is a function of flow rate. For any positive displacement motor the higher the flow rate the higher the bit speed. Fig-4 looks at a power curve for the A700GT5: 6 motor. This is a 7" motor with a 5:6 lobe configuration. The top chart plots RPM and torque against operating differential pressure. The bottom chart plots the corresponding horsepower. It should be noted that recommended operating pressure is 80% of maximum. This is done to emphasize the importance of maximizing the run length. Like any motor the expected life will decrease when run flat out. It should also be noted how the RPM decreases with increasing differential pressure. This is due to partial fluid leakage across the rotor stator seal. If the lines were to be extrapolated they would reach zero which is the stall condition. It is important therefore that the charts be used for determining the power output of the motor at any given flow rate and differential pressure. It would be very misleading to calculate based on free running bit speed and maximum torque as the conditions never co-exist.

In order to take advantage of the power of the GT range of motors it is important that the drilling unit is able to provide sufficient horsepower.

A series of wells drilled in East Texas with a variety of drilling rigs illustrated this point. Fig-5 plots average ROP against flow rate for both the A700GT and A675XP motors in 8 1/2" hole with a PDC bit. Where flow rate was limited to 450 GPM the ROP averaged less than 50 ft/hr. On the bigger rigs with flow rates of 575 GPM it was possible to average over 75 ft/hr. For this motor the bit speed increased by 50RPM from one end of the flow range to the other making a significant impact on drilling performance. At the lower end of the flow range it was more economic to run the XP motor.

Deep, Hard and Hot

A deep gas well in Wyoming gave the opportunity to demonstrate the benefits of proper bit and motor selection in 12 1/4" hole. The well required drilling a radically changing cretaceous sand/shale section at depth using oil based mud with circulating temperatures of up to 300degrees F. Analysis of offset data indicated that problems had been encountered with tooth breakage due to excessive bit rotary speed and excessive torque during drilling. A recommendation was given to the client that by simply matching the proper motor with the appropriate bits within specified formations it would be possible to improve ROP and extend the run life.

Initially a high speed A962HS PowerPak motor and a Hycalog 444 diamond impregnated bit was recommended for the first two formations to be encountered. The results with this combination resulted in 767 feet and 244 hours drilling. The clients' evaluation was viewed as excellent.

The next formation required a slower speed motor and a PDC bit. An A962 7:8 GT slow speed motor was run with an initial increase in penetration rate but severe slip/stick was encountered and thus the assembly was pulled in order to run an insert bit. The A962 7:8 GT was run. The power characteristics of this motor allowing high weight on bit to be run with very low bit speed. As such the life of the insert bit could be maximized. Three insert bits were used achieving run lengths of 130, 168 and 147 hours. Weight on bit of up to 60,000 lbs. was used with total bit rotational speed (motor and surface) being kept to 100RPM. Footage for the 3 runs was 1339 feet. Once the third run was completed the formations were again suitable for drilling with PDC bits. Still using the A962GT7:8 the remaining 2527 feet of this hole section were drilled in three bit runs in 719 hours. Proper sizing of the rotor/stator interference in the high temperature oil based mud insured durability of the motors with an average run length of 240 hours. The low bit speed of the 7:8 power section assuring the durability of the PDC bits.

Conclusions

The positive displacement motor is available in a wide range of configurations. Advances in manufacturing capability have allowed a new generation of multistage performance power sections that can be matched to the requirement of the drill bit for any given drilling application.

A systems approach to bit and motor selection will optimize the economics of a bit run. Hydraulics must be planned to take advantage of the power from the motor. The motor must be selected to allow the use of drilling parameters that provide both high ROP and maximum run length. Setting up the motor for the particular downhole conditions has extended the temperature range for successful performance drilling.

In hard rock conditions the high torque slow speed motor has maximized the effectiveness of insert bits extending run length beyond previously accepted norms.

Using a motor in vertical drilling applications allows maintaining minimum surface RPM with significant decrease in drillstring fatigue particularly through minimizing the incidence of BHA whirl.

Figures

Fig. 1- Evolution of 4 3/4" motors.

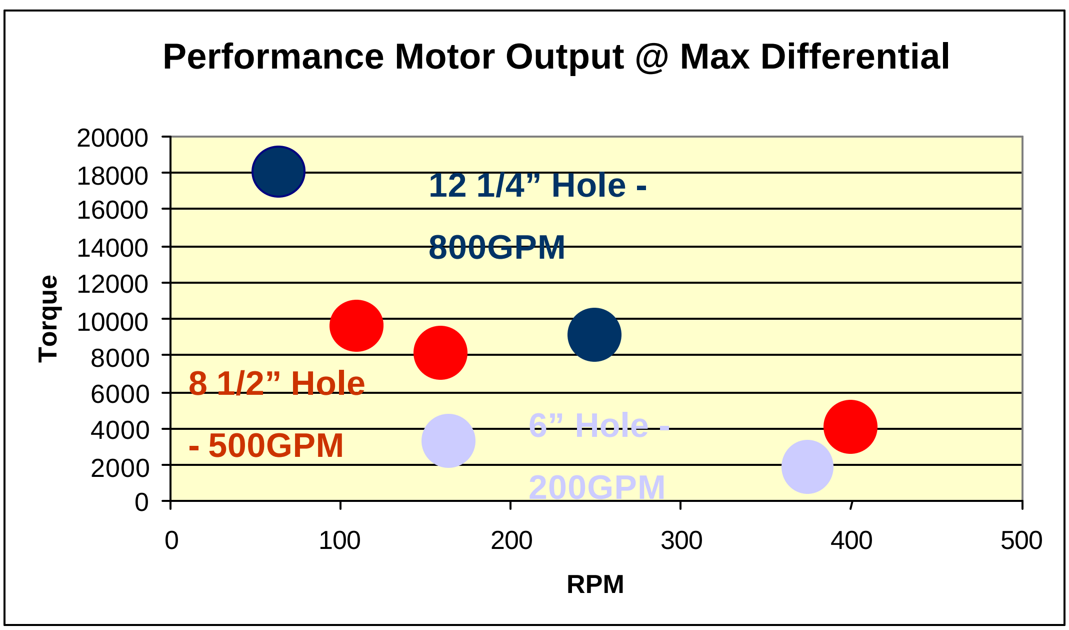

Fig. 2- Performance motor output.

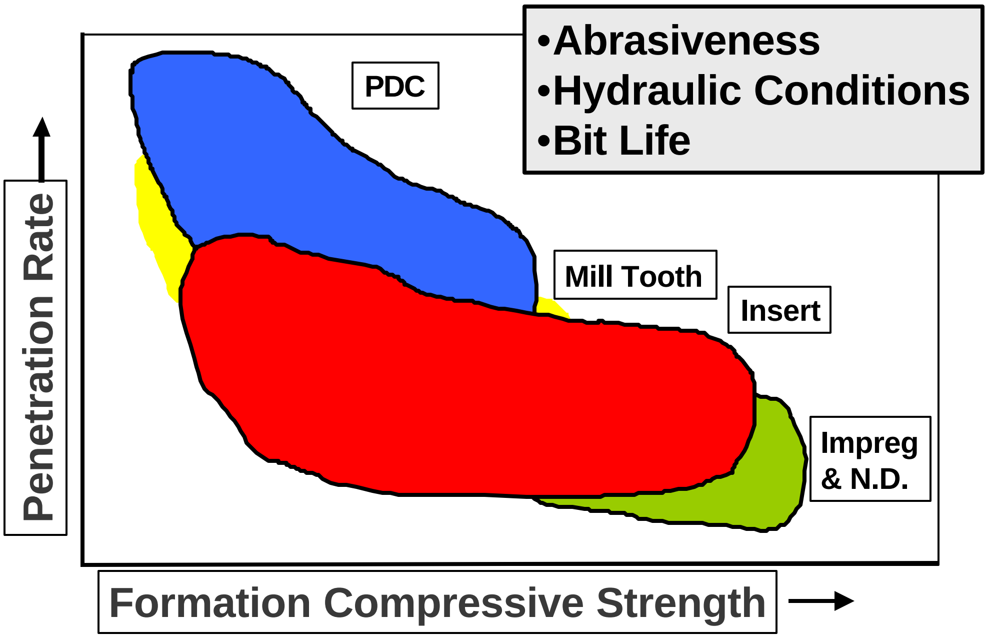

Fig. 3- Relationship of formation compressive strength and bit selection

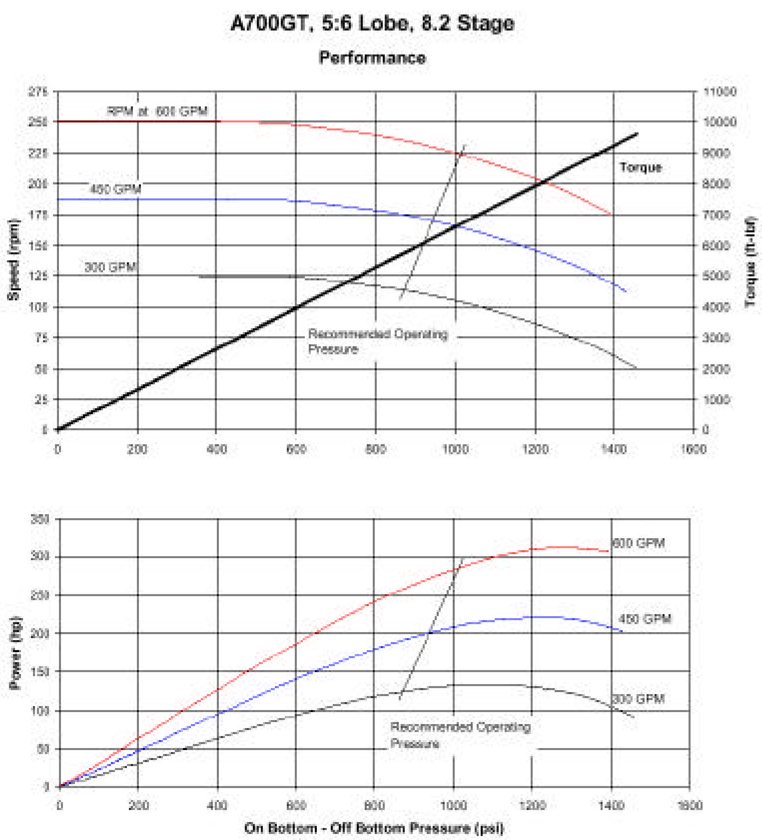

Fig. 4- Power Curve for the A700GT5:6 motor

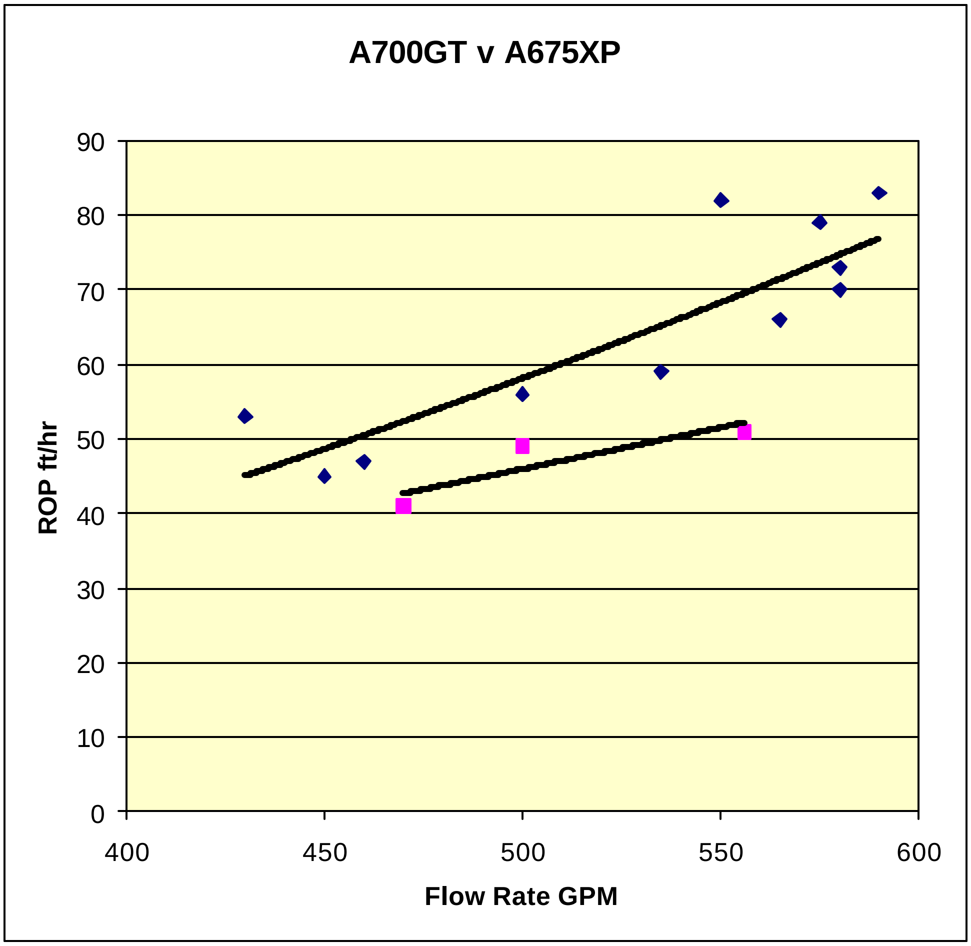

Fig. 5 ROP vs flow rate