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Size and configuration of mud motor drilling affects the optimum power outputs

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A B S T R A C T

The present invention provides a modular drilling assembly having a module for contactless power and data transfer over a nonconductive gap between rotating and non-rotating members of a steering module. The gap usually application data contains a non-conductive fluid, such as drilling fluid, or oil for operating hydraulic devices in the down-hole tool. The down-hole tool in one embodiment is a modular drilling assembly wherein a drive shaft is rotated by a down-hole motor to rotate a drill bit attached to the bottom end of the drive shaft. Generally, there are two main sections on mud motor which are bearing section and power section. The power section generally includes a housing which houses a motor stator within which a motor rotor is rotationally mounted. The power section converts hydraulic energy into rotational energy by reverse application of the Moineau pump principle. The stator has a plurality of helical lobes which define a corresponding number of helical cavities. The rotor has a plurality of lobes which number one fewer than the stator lobes and which define a corresponding plurality of helical cavities. Generally, the greater the number of lobes on the rotor and stator, the greater the torque generated by the motor. Fewer lobes will generate less torque but will permit the rotor to rotate at a higher speed. Based on torque and rotate speed, determine the optimum power can be produced by power section configurations.

1. Introduction

In general, the present invention provides a modular drilling assembly having a module for contactless power and data transfer over a nonconductive gap between rotating and non-rotating members of a steering module. The gap usually application data contains a non-conductive fluid, such as drilling fluid, or oil for operating hydraulic devices in the down-hole tool. The down-hole tool in one embodiment is a modular drilling assembly wherein a drive shaft is rotated by a down-hole motor to rotate a drill bit attached to the bottom end of the drive shaft. A substantially non-rotating sleeve around the drive shaft includes at least one electrically-operated device. The drilling assembly is modular in that it includes at least one steering module at the bottom end of the drilling assembly that

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has at least one steering device module that provides power to the force application member. A power and data communication up-hole of the steering module provides power to the steering module and data communication between the drilling assembly and the surface (Krueger et al., 2002). Also the present invention relates to oil and gas well drilling and more particularly, to an improved mud motor for drilling oil and gas wells and for drilling through obstructions, plugs and the like, in oil and gas wells where in a high torque, low speed (i.e. low r.p.m.) motor is operated with a reciprocating valve and piston arrangement that uses differential fluid pressure for power and a transmission that isolates impact generated by the reciprocating valve and piston from the drill bit. In desirably low impact situations, there is a need for a drill motor that operates with well drilling fluid or drilling mud. Such "mud motors" have been commercially available for a number of years. All motors referred to as "mud motors" are of multi-lobe positive displacement operating on the "Moineau" principal. One of the limitations of these "mud motors" is their inability to operate in temperatures above about 250° Fahrenheit. Another limitation of such "mud motors" is that they cannot operate for any length of time on nitrogen or nitrified foam. They typically include a rotating member that is powered with the drilling mud as it flows through an elongated tool body. Suppliers of such "mud motors" include Drillex, Norton Christiansan, and Baker (Hipp, 2000).

To recover oil and gas from subsurface formations, well bores (also referred to as boreholes) are drilled by rotating a drill bit attached at an end of a drill string. The drill string includes a drill pipe or a coiled tubing (referred herein as the "tubing") that has a drill bit at its down-hole end and a bottom hole assembly (BHA) above the drill bit. The well-bore is drilled by rotating the drill bit by rotating the tubing and/or by a mud motor disposed in the BHA. A drilling fluid commonly referred to as the "mud" is supplied under pressure from a surface source into the tubing during drilling to wellbore. The drilling fluid operates the mud motor (when used) and discharges at the drill bit bottom. The drilling fluid then returns to the surface via the annular space (annulus) between the drill string and the wellbore wall or inside. Fluid returning to the surface carries the rock bits (cuttings) produced by the drill bit as it disintegrates the rock to drill the wellbore (Weirich et al., 2001).

Down-hole motors assemblies are well known in the drilling arts. Mud motors are one well known type of down-hole motors. Mud motors are used to supplement drilling operation by turning fluid power into mechanical torque to a drill bit. The mud is used to cool and lubricate the drill bit, to carry away drilling debris and to provide a mud cake on the walls of the annulus to prevent the hole from sloughing in upon itself or from caving in all together. Mud motors operate under very high pressure and high torque operations and are known to fail in certain, predictable ways. The failure of mud motor is very expensive, as the whole drill string must be pulled out of the bore hole in order to bring the mud motor to the surface where it can be repaired and replaced. This is very time occur with prior art mud motors include; seal failure resulting in drilling mud motor in the universal joint in the transmission section; pressuring up, often called hydraulically locking, due to either fluid or gas being trapped within the confines of the tool itself, and broken bearing mandrels and resulting mud invasion into the bearings (Blair et al., 2004).

2. Literature Review

As mentioned earlier, the gap may contain a non-conductive fluid, such as drilling fluid or oil for operating hydraulic devices in the down-hole tool. The down-hole tool, in one embodiment, is a drilling assembly wherein a drive shaft is rotated by a down-hole motor to rotate the drill bit attached to the bottom end of the drive shaft. A substantially non-rotating sleeve around the drive shaft includes a plurality of independently-operated force application members, wherein each such member is adapted to be moved radially between a retracted position and an extended position. The force application members are operated to exert the force required to maintain and/or alter the drilling direction. In the prefer system, a common or separate electrically-operated hydraulic unit provide energy (power) to the force application members. An inductive coupling transfer device transfers electrical power and data between the rotating and non-rotating members. An electronic control circuit or unit associated with the rotating member controls the transfer of power and data between the rotating member and the non-rotating member. An electrical control circuit or unit carried by the non-rotating member controls power to the devices in the non-rotating member and also controls the transfer of data from sensors and devices carried by the non-rotating member to the rotating member. In an alternative embodiment of the invention, an inductive coupling device transfers power from the non-rotating housing to the rotating drill shaft. The electrical power transferred to the rotating drill shaft is utilized to operate one or more sensors in the drill bit and/or the bearing assembly. A control circuit near the drill bit controls transfer of data from the sensors in the rotating member to the non-rotating housing. The inductive coupling may also be provided in a separate module above the mud motor to transfer power from a non-rotating section to the rotating member of the mud motor and the drill bit. The power transferred may be utilized to operate devices and sensors in the rotating sections of the drilling assembly, such as the drill shaft and the drill bit. Data is transferred from devices and sensors in the rotating section to the non-rotating section via the same or a separate inductive coupling. Data in the various embodiments is preferably transferred by frequency modulation. The drilling assembly is modular, in that relatively easily connectable modules make up the drilling assembly. The modular drilling assembly includes at least a steering module that carries the drill bit and includes a non-rotating sleeve that includes a plurality of pluggable steering device modules. A power and data communication module up-hole of the steering module provides power to the steering module and two-way data communication between the steering module and the remaining drilling assembly. A subassembly containing multi propagation sensitivity sensors and gamma ray sensors is disposed up-hole of the steering module. This subassembly may include a memory module and a vibration module. A directional module containing sensors for determining the drilling assembly direction is preferably disposed up-hole of the resistivity and gamma sensor subassembly. Modular subassemblies make up portions of the steering assembly. The primary electronics, secondary electronics inductive coupling transformers of the steering module are also individual pluggable modules (Krueger et al., 2002).

A wellbore is formed in the earth with an elongated, non – rotating tubular drill stem which may consist of a well casing or liner and including an expendable sub and reamer bit part connected to the lower distal end of the drill stem. A retrievable drilling fluid operated motor and drive member assembly are disposed in the drill stem. The motor and drive member include pressure responsive mechanism for engagement with and disengagement from the reamer bit part to rotatable drive the reamer bit part and a central bit part connected to the drive member without rotating the casing type drill stem. The motor, drive member and central bit part may be retracted from the drill stem upon completion of drilling operations without retrieving the expendable reamer bit part (Winfree, 1995). A drill string typically comprises a tubular which is terminated at a lower end by a drill bit, and terminated at an upper end at the surface of the earth by a "drilling rig" Which comprises draw works and other apparatus used to control the drill string in advancing the borehole. The drilling rig also comprises pumps that circulate drilling fluid or drilling "mud" downward through the tubular drill string. The drilling mud exits through opening in the drill bit, and returns to the surface of the earth via the annulus defined by the wall of the borehole and the outer surface of the drill string. A mud motor is often disposed above the drill bit. Mud flowing through a rotor-stator element of the mud motor imparts torque to the bit thereby rotating the bit and advancing the borehole. The circulating drilling mud performs other functions that are known in the art. These functions including providing a means for removing drill bit cutting from the borehole, controlling pressure Within the borehole, and cooling the drill bit (Konschuh et al., 2011).

A down-hole drilling motor is provided with a bearing unit which supports the output shaft in such an inclined position relative to the motor housing, that the central axis of the output shaft intersects the longitudinal axis of the motor housing at a point of intersection located below the lower end of the housing. Directional drilling of a borehole is carried out by actuating a drill bit by means of the down-hole drilling motor, and simultaneously therewith rotating the drill string and consequently also the motor housing-over periods that are preceded and succeeded by selected periods over which the drill string is not rotated (Kamp, 1985). To obtain hydrocarbons such as oil and gas, boreholes or wellbores are drilled by rotating a drill bit attached to the bottom of a drilling assembly (also referred to herein as a "Bottom Hole Assembly" or ("BHA"). The drilling assembly is attached to the bottom of tubing, which is usually either a jointed rigid pipe or a relatively flexible spoolable tubing commonly referred to in the art as "coiled tubing." The string comprising the tubing and the drilling assembly is usually referred to as the "drill string." When jointed pipe is utilized as the tubing, the drill bit is rotated by rotating the jointed pipe from the surface and/or by a mud motor contained in the drilling assembly. In the case of coiled tubing, the drill bit is rotated by the mud motor. During drilling, a drilling fluid (also referred to as the "mud") is supplied under pressure into the tubing. The drilling fluid passes through the drilling assembly and then discharges at the drill bit bottom. The drilling fluid provides lubrication to the drill bit and carries to the surface rock pieces disintegrated by the drill bit in drilling the wellbore. The mud motor is rotated by the drilling fluid passing through the drilling assembly. A drive shaft connected to the motor and the drill bit rotates the drill bit (Krueger et al., 2002).

It has been recognized that when a down-hole motor is rotating the bit on bottom while weight-on-bit (WOB) is being applied thereto, a reactive torque in the counter clockwise direction is applied to the housing of the motor, which includes the bent housing. The level of such counter torque is directly proportional to the weight-on-bit, and has its maximum level at motor stall. Such reactive torque, and the presence of a bend point in the bent housing, causes lateral forces to be applied to the bit which tends to change the direction of the bore hole. However, to control the direction, there must be a way to orient the bend point about the axis of the bore hole. As noted above, this is accomplished when using a conventional drill pipe string by simply turning it at the surface. However, coiled tubing cannot be manipulated in this manner. The present invention provides a means and method of orienting the bent housing and its bend point down-hole, which enables a directional drilling tool string to be run on coiled tubing (Eddison et a1., 1994). When drilling or coring holes in subsurface formations, it is often desirable to be able to vary and control the direction of drilling, for example to direct the borehole towards a desirable target or to control the direction horizontally within the payzone once the target has been reached. It may also be desirable to correct for deviations from the desired direction when drilling a straight hole, or to control the direction of the hole to avoid obstacles. (Russell et a1., 1993). The two-basic means of drilling a borehole are rotary drilling, in which the drill bit is connected to a drill string which is rotatable driven from the surface, and systems where the drill bit is rotated by a down-hole motor, either a turbine or a positive displacement motor. Hitherto, fully controllable directional drilling has normally required the use of a down-hole motor, and there are a number of well-known methods for controlling the drilling direction using such a system (Barr et al., 1996). When drilling oil and gas wells for the exploration and production of hydrocarbons, it is very often necessary to deviate the well-off vertical and in a particular direction. Such deviation may be required, for example, when drilling from land to explore formations beneath the sea or below a lake, or in the case of oil and gas production offshore, when drilling 20 or 30 wells from the same platform, each going in a different direction to gain the widest coverage of the hydrocarbon bearing structure. The latter can result in wells being as much as 3 to 4 miles apart at the point where they pass through the production zone (Noble, 1992).

Referring initially to Fig. **1**, a borehole **10** is shown extending downward, substantially vertically, from a surface site **11** where a drilling rig (not shown) is located. At some depth below the surface, depending on geology and other factors, the borehole **10** is shown being curved through a section **14** that eventually will bring its outer end to the horizontal. The radius of curvature R of the section **14** is relatively short, and through use of the present invention can be in the order of about 60 feet for an assembly that is used to drill a borehole having a diameter of 6 1/8". The curved section **14** is drilled with an articulated drilling motor assembly **15** that is constructed in accordance with the present invention. The motor assembly **15** is run on a drill string **16** that typically includes a length of heavy drill collars **17** suspended below a length of drill pipe **18**. A lower section of drill pipe 18' is used in the curved section **14** of the borehole **10**, since the drill collars usually are too stiff to negotiate the curve and still function to apply weight. A drill bit **20** on the lower end of the motor assembly **15** can be either a rolling cone or a diamond device. The power section **21** of the motor assembly **15** preferably is the well-known Moineau-type design where a helical rotor rotates in a lobed stator in response to drilling mud being pumped through it under pressure. The lower end of the rotor is coupled by a universal-joint shown schematically at **24** to an intermediate drive shaft **73** whose lower end is coupled by another universal joint **25** to the upper end of a hollow mandrel **27**. The mandrel **27** is joumaled for rotation in a bearing assembly **28**, and the drill bit **20** is attached to a bit box **30** on the lower end of the mandrel **27** (Eddison, 1996).

A drilling motor includes a non-elastomeric stator and rotor which are dimensioned for negative or Zero interference. The amount of negative interference between the rotor and the stator is determined by the largest solid particle expected to pass through the motor. The negative interference or gap between the rotor and the stator is preferably at least two times the greatest particle size. Stators are made by machining or casting stainless steel and are fabricated in sections having lengths of 20 to 40 centimeters. The sections are indexed so that each section may be properly aligned with another. The sections are aligned and welded together to form a motor stator of conventional length. Prior art Fig. **2** show details of the power section **18** of the down-hole motor. The power section **18** generally includes a housing **22** which houses a motor stator **24** within which a motor rotor **26** is rotationally mounted. The power section **18** converts hydraulic energy into rotational energy by reverse application of the Moineau pump principle. The stator **24** has a plurality of helical lobes, **24**a – **24**e, which define a corresponding number of helical cavities, **24**a‘– **24**e‘. The rotor **26** has a plurality of lobes, **26**a – **26**d, which number one fewer than the stator lobes and which define a corresponding plurality of helical cavities **26**a‘– **26**a". Generally, the greater the number of lobes on the rotor and stator, the greater the torque generated by the motor. Fewer lobes will generate less torque but will permit the rotor to rotate at a higher speed. (Pafitis et al., 2001).

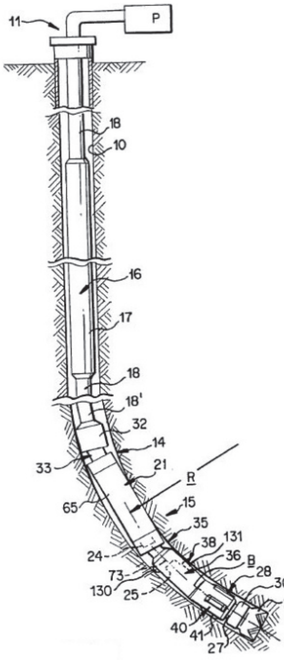

Fig. 1. Drilling Motor Assembly

According to Han & Wang (2014), measuring method for motor torque is calculated by:

$$T = \frac{P}{\omega} \tag{1}$$

where:

T = Torque (Nm)
P = Power (Watt)
ω = Angular Velocity (Rad/s)

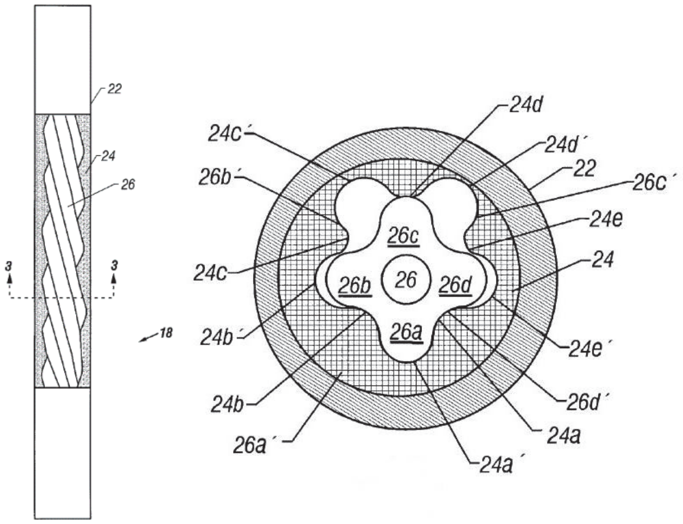

Fig. 2. Stator and Rotor with 4:5 lobes configuration.

3. Research Methodology

This present study analyzes the power section (stator and rotor) configuration affects torque, power and angular speed output on mud drilling motor. Then, put the dimension of motor as a variable that also can affect the motor performance. In this case, we have two motor sized which are 6-inch diameter and 9-inch diameter and four kinds of the power section configuration in this paper, which are: (a) 2:3 lobes configuration. (b) 5:6 lobes configuration. (c) 6:7 lobes configuration. (d) 7:8 lobes configuration. Each configuration will produce different torque and angular velocity.

4. Result and Discussion

4.1. Torque

Torque is the twisting force that tends to cause rotation. The point where the object rotates is known as the axis of rotation. It also happens in mud motor drilling; each motor size and power section configuration will produce different number of torque. Torque data are shown in Tables 1 and 2.

Table 1. Torque data for each power section configuration on 6-inch motor

Power Section	Torque (N.m)
2:3 lobes Configuration	4203.03
5:6 lobes Configuration	8812.81
6:7 lobes Configuration	14913.99
7:8 lobes Configuration	16373.54

Table 2. Torque data for each power section configuration on 9-inch motor

Power Section	Torque (N.m)
2:3 lobes Configuration	9761.88
5:6 lobes Configuration	11660.03
6:7 lobes Configuration	14981.78
7:8 lobes Configuration	17625.63

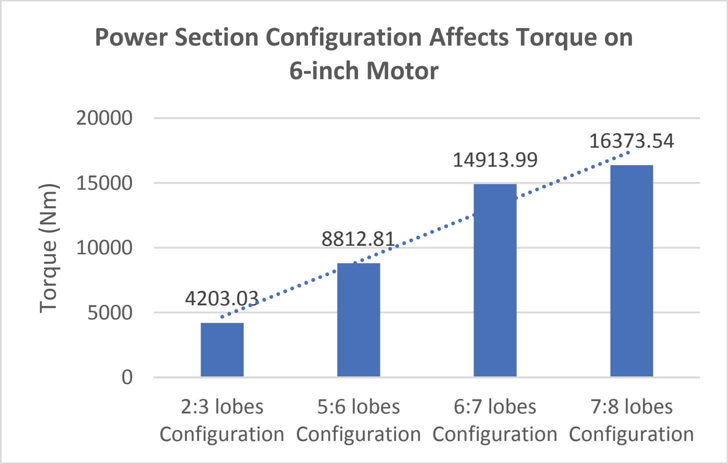

Fig. 3. Torque are produced by each power section configuration on 6-inch Motor

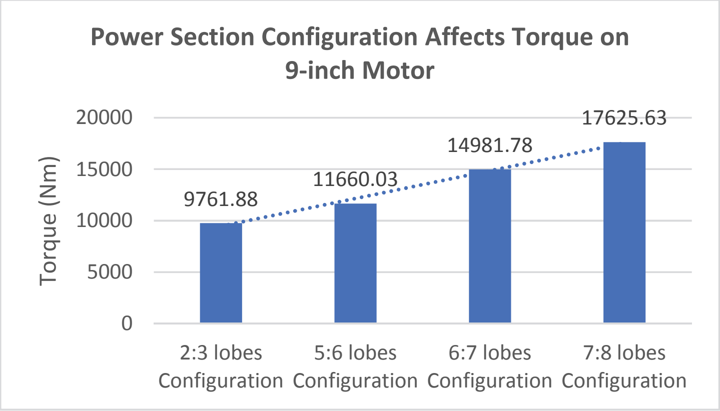

Fig. 4. Torque are produced by each power section configuration on 9-inch Motor

From Tables 1-2 and Figs. 3 and 4, we can conclude that number of lobes in power section configuration is directly proportional with torque produced. The greater number lobes, the greater torqued produced.

4.2. Angular Velocity

In physics, the angular velocity is defined as the rate of change of angular displacement and is a vector quantity (more precisely, a pseudo vector) that specifies the angular speed (rotational speed) of an object and the axis about which the object is rotating. This speed can be measured in the SI unit of angular velocity, radians per second, or in terms of degrees per second, degrees per hour, etc. It also happens in mud motor drilling; each motor size and power section configuration will produce different number of angular velocity. Angular velocity data are shown in Tables 3 and 4.

Table 3.
Angular velocity data for each power section configuration on 6-inch Motor

Power Section	Angular Velocity(rad/s)
2:3 lobes Configuration	43.28
5:6 lobes Configuration	35.67
6:7 lobes Configuration	29.35
7:8 lobes Configuration	20.75

Table 4. Angular velocity data for each power section configuration on 9-inch Motor

Power Section	Angular Velocity(rad/s)
2:3 lobes Configuration	40.78
5:6 lobes Configuration	33.59
6:7 lobes Configuration	28.55
7:8 lobes Configuration	26.67

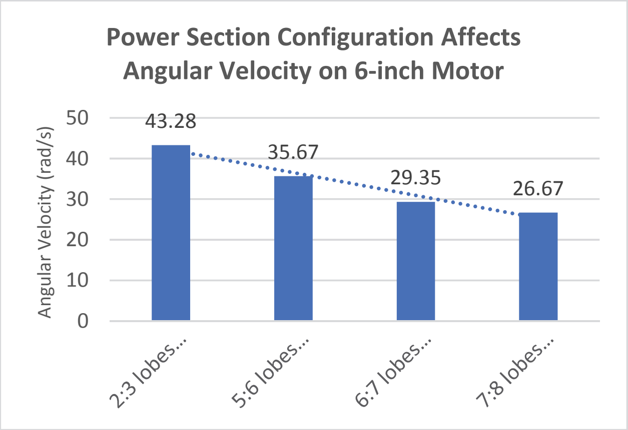

Fig. 5. Angular Velocity are produced by each power section configuration on 6-inch Motor

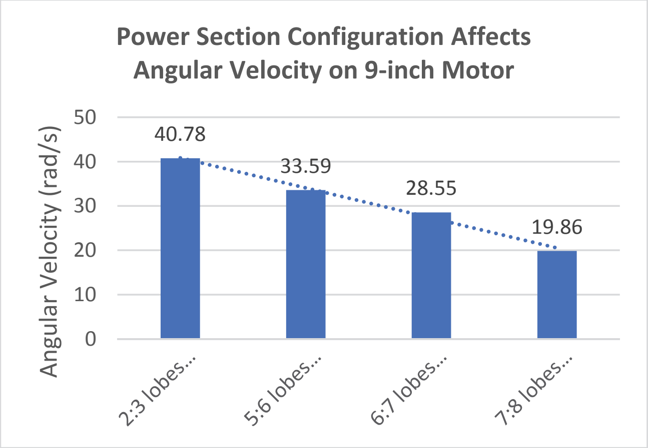

Fig. 6. Angular Velocity are produced by each power section configuration on 9-inch Motor

From Tables 3-4 and Figs. 5 and 6, we can conclude that number of lobes in power section configuration is inversely proportional with angular velocity produced. The greater number lobes, the smaller angular velocity produced.

4.3. Mud Motor Power

From torque and angular velocity data, calculate the mud motor power.

Table 5. 6-inch Mud Motor Power

Power Section	Power (Watt)	Power (HP)
2:3 lobes Configuration	181,907.14	247.32
5:6 lobes Configuration	314,352.93	427.40
6:7 lobes Configuration	437,725.61	595.14
7:8 lobes Configuration	339,750.96	461.93

Table 6. 9-inch Mud Motor Power

Power Section	Power (Watt)	Power (HP)
2:3 lobes Configuration	398,089.47	541.25
5:6 lobes Configuration	391,660.41	532.51
6:7 lobes Configuration	427,729.82	581.55
7:8 lobes Configuration	470,075.55	639.12

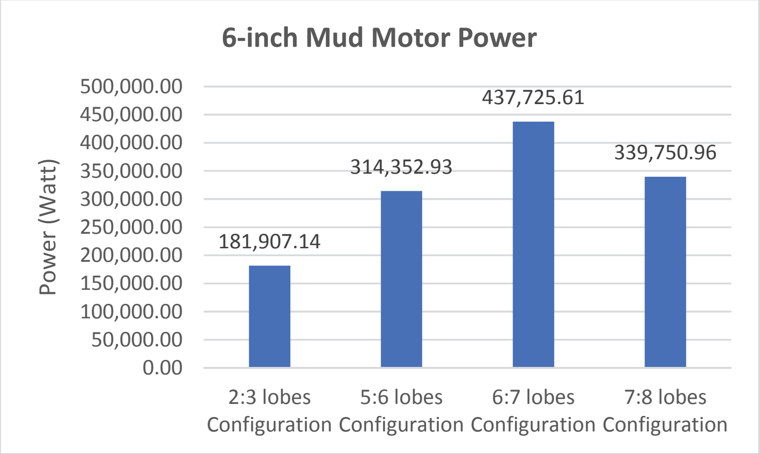

Fig. 7. 6-inch Mud Motor Power are produced by each power section configuration.

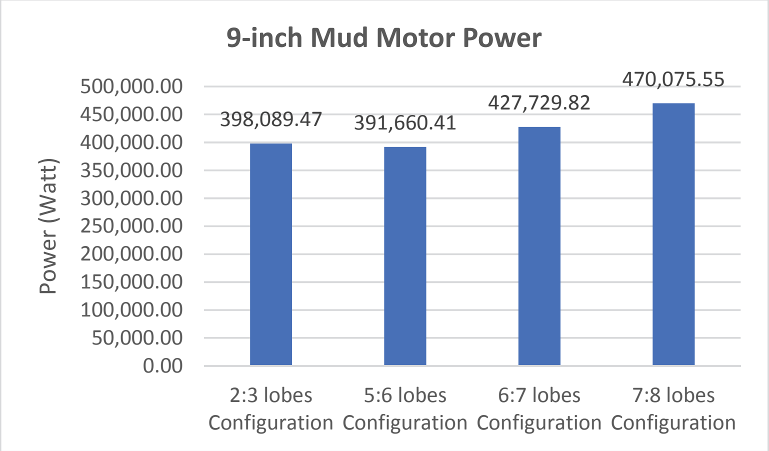

Fig. 8. 9-inch Mud Motor Power are produced by each power section configuration.

From Tables 5-6 and Figs. 7 and 8, we have two different optimum powers from different motor sizes. We can conclude that optimum power on 6-inch motor is produced by power section with 6:7 lobes configuration. The optimum power achieved 437,725.61 watts or 595.14 HP. But, for 9-inch motor the optimum power can be found on 7:8 lobes configuration. The optimum power achieved 470,075.55 watts or 639.12 HP.

5. Conclusion

This paper has presented an empirical investigation about the power section configuration affects the number of torque, angular velocity and power produced on mud motor drilling. Especially the number of lobes in power section will influence the number of torque, angular velocity and power produced. So we can conclude that: (a) Number of lobes in power section configuration is directly proportional with torque produced. The greater number lobes, the greater torqued produced. (b) Number of lobes in power section configuration is inversely proportional with angular velocity produced. The greater number lobes, the smaller angular velocity produced. (c) Optimum power on 6-inch motor is produced by power section with 6:7 lobes configuration.

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