

Mitigating Bit-Related Stick-Slip With A Torsional Impact Hammer

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Abstract

The phenomenon of stick-slip is well researched and documented within the drilling industry. Bit-related stick-slip is often a problem when drilling hard formations with a Polycrystalline Diamond Compact (PDC) fixed-cutter drill bit. Under optimum drilling conditions, the PDC bit shears formation with a constant depth of cut (DOC). When a harder formation is encountered the bit loses DOC and more weight-on-bit (WOB) must be added to engage the PDC cutters in formation. Many times, however, the reactive torque of the formation cannot be overcome immediately – in this case the bit slows or stops (stick) while torque is stored in the drill string until the torque required to fail formation is achieved and the bit violently rotates (slip). This action can cause damage to PDC cutters and other drill string components, resulting in reduced bit and tool life as well as poor rate of penetration (ROP).

Traditional methods for mitigating stick slip involve adjusting operating parameters to avoid the stick-slip phase, pacifying the PDC bit by using higher blade counts, higher backrakes, etc., or even by using less-efficient roller cone or diamond-impregnated bits. These methods have only been marginally successful and reduce overall drilling efficiency and lead to reduced potential ROP.

A torsional impact hammer has shown to be effective in reducing or eliminating bit related stick-slip and inefficient drilling in difficult formations. The following paragraphs will discuss the stick-slip phenomenon, traditional methods to combat stick-slip, and how the torsional impact hammer functions to reduce bit related stick slip and improve drilling efficiency. A case study of performance improvements is presented.

Introduction

Stick-slip is an issue facing drillers throughout the world, bleeding energy and lowering the efficiency of drilling as well as causing major damage to downhole tools and drill strings (Robne et al).

A torsional impact hammer is a downhole tool that transfers hydraulic energy from the drilling fluid into a torsional impact which is imparted to the drill bit. This can significantly reduce the incidence of stick-slip, improving drilling efficiency and greatly reducing fatigue and damage to drilling components.

The following pages will describe the stick-slip

phenomenon and the causes and effects thereof, the operation and benefits of the torsional impact hammer, and a case study of performance improvements gained by utilizing the torsional impact hammer in a drilling application prone to stick-slip.

Stick-Slip Definition

Classic Definition of Stick-Slip

The term stick-slip is typically used to describe the buildup of potential energy and its subsequent release once the static friction between two contacting surfaces is overcome by an outside force (Davidson). A classic example is illustrated below in Figure 1 using a block with a spring attached to it. As the spring is pulled it begins to stretch until the point at which the force being applied exceeds that of the static friction between the block and the surface it is sitting on. The block surges forward potentially even compressing the spring until such a point that the static friction becomes greater than the external force once again causing the block to stop moving.

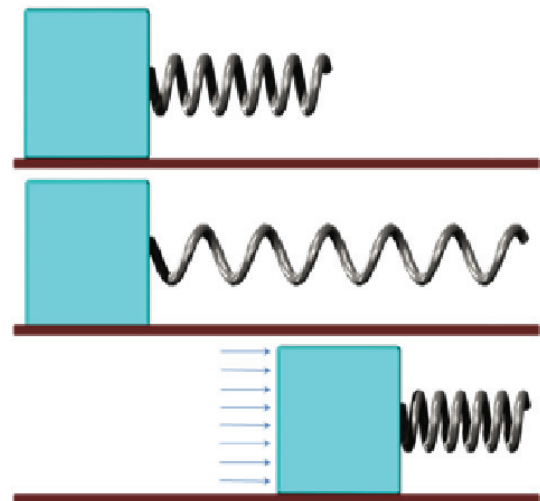


Figure 1. Classic frictional stick-slip (Davidson).

Stick-Slip Relating to Drilling

Stick-slip as it is known in drilling situations can occur throughout the drill string for many reasons, but the most prevalent form of stick-slip and the form that this discussion focuses on occurs at the drill bit and will be referred to as bit-related stick-slip.

The example provided in Figure 1 is an example of linear stick-slip, but stick-slip in a drilling situation, including bit-related stick-slip, is a torsional vibration. Stick-slip is initiated when the energy (or torque) being delivered to the bit by the drill string is not sufficient to overcome the formation being drilled – at this point the bit slows or stops in the “stick” phase. The torque builds in the drill string resulting in twists until enough torque has been developed to fail the formation, at which point the drill bit breaks free from the “stick” phase and rapidly accelerates, rotating at several times the intended rotary speed in the “slip” phase. This action is demonstrated in Figure 2. The drilling assembly will continue to alternate between the “stick” and “slip” phases until operating parameters or formations change.

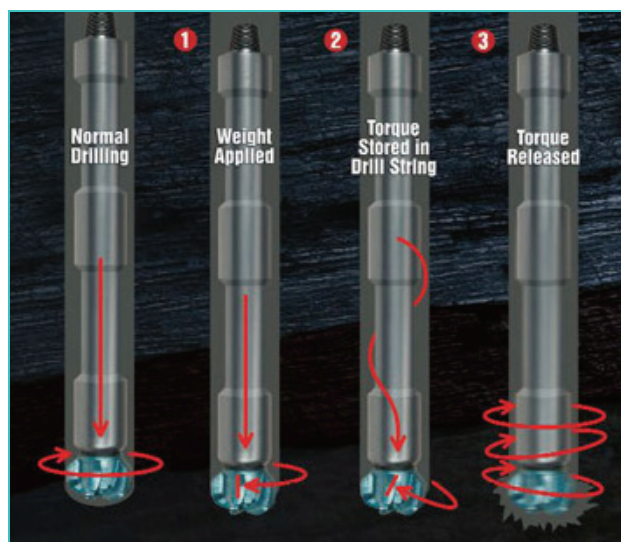


Figure 2. Stick-slip in a drilling environment.

Modes and Causes of Stick-Slip

Formations

The stick-slip phenomenon is most typically related to “hard” (higher compressive strength) formations. These include but are not limited to sandstone, limestone, and dolomite. As described above, the high strength of these formations does not typically allow the drill bit to fail the rock efficiently under normal parameters that would be used to drill lower-strength “soft” rock such as shales. The axial load on the drill bit is not sufficient to engage the cutters in the formation such that the penetration rate is acceptable. As the axial load is increased to counter this, the drill bit advances into the formation and engages the cutters; however, due to the volume of high-strength rock the drill bit is attempting to remove at this depth of cut, the rotational energy applied to the drill bit may not be sufficient to advance the bit on its cutting path. In this case the bit may slow or stop, until energy is built in the drill string and BHA sufficient to fail the rock.

Stick-slip is not exclusive to hard or difficult-to-shear formations. In many deep wellbores, such as the one described in the case study to follow, high drilling mud weights are used to contain high-pressure fluids within the

formation and keep them from infiltrating the wellbore. This results in a tall column of dense fluid, the weight of which is standing on the bit/rock interface. This can cause even relatively soft formations to behave as hard formations by increasing the confined compressive strength. Another issue in these deep wellbores is the massive amount of relatively thin drill string components, which due their length can be subject to sometimes severe vibrations. Vibrations in the drill string bleed energy that could be employed at the drill bit to fail formation, resulting in higher rates of vibration and stick-slip at the bit.

Friction in the Drill String

Although this paper focuses on bit-related stick-slip, it is worth mentioning that the phenomenon can be encountered in the drill string as well. Any components that are in contact with the wellbore – stabilizers, motor kick pads, and even drill pipe – develop static or dynamic friction with the wellbore. This can not only cause stick-slip to occur at these locations independent of the drill bit, it can also reduce the available axial and torsional energy at the drill bit – thereby accelerating the incidence of stick-slip at the drill bit.

Damage to the Drill Bit

Stick-slip can severely shorten PDC cutter life, resulting in poor runs and severe dull conditions in many cases. When torsional energy is built in the drill string to a sufficient level to fail formation and the bit “slips”, the bit can rotate at several times the intended rotary speed. This rapid impact to the cutter can cause breakage, as well as accelerate cutter wear in abrasive formations, especially when the cutter has suffered previous impact damage. In addition, the torsional vibration of stick-slip can lead to axial and lateral vibrations, such as backward whirl (Leine and van Campen), further damaging the drill bit. Once the cutters have been damaged, the energy required to fail the formation and maintain sufficient penetration rate becomes much higher as the efficiency of the drill bit is compromised. This loss of efficiency only exacerbates the stick-slip issue. Figure 3 demonstrates a PDC bit with normal wear developed by drilling an abrasive formation, and Figure 4 shows a PDC bit with damage typical of stick-slip.



Figure 3. Typical PDC wear.



Figure 4. Impact damage typical of stick-slip failure.

Damage to Drill String Components

Damage to expensive equipment is not limited to the drill bit. Downhole motors or rotary steerable systems, measurement tools, stabilizers, drill collars, and drill pipe are all string components that can be damaged by stick-slip. Severe stick-slip can cause a downhole motor to stall, building pressure and many times causing the motor to “chunk”, or lose rubber from the stator assembly – this loss can severely decrease the efficiency of the motor such that it does not function and the assembly must be tripped. Rotary steerable systems and measurement tools such as Measurement-While-Drilling (MWD) and Logging-While-Drilling (LWD) common in today’s drilling programs contain sensitive electronic equipment that can be damaged by vibrations resulting from stick-slip. Stabilizers can see excessive wear similar to what is seen on the drill bit. Finally, tubulars such as drill collars and drill pipe, as well as all of the components listed above, see fatigue to connections as the drill string is subjected to torque fluctuations. In severe cases when the torque in the drill string is released and the string rotates violently, connections can “back-off” and separate one tubular from another.

Drilling Efficiency

Stick-slip is detrimental to overall drilling efficiency in several aspects. Even with a sharp (undamaged) PDC bit, during stick-slip the bit may not be turning for a large percentage of drilling time, which means the bit cannot advance into the formation – this results in a low overall ROP. When the bit is damaged due to stick-slip, the drilling efficiency of the bit is reduced as more energy is required to fail the formation with damaged cutters. As described above, downhole motor stator loss and the associated loss of efficiency further bleeds energy from the system. Finally, the stick-slip-related vibrations propagated through the drill string can reduce the overall energy and efficiency substantially.

Common Methods for Mitigating Stick-Slip

As evidenced by the paragraphs above, stick-slip can be severely detrimental to a drilling program by decreasing penetration rates, bit life, and downhole tool life. Operators

and drilling contractors often seek to mitigate stick-slip through bit design and selection, operating parameters, and BHA design.

Bit Features

An assortment of PDC design characteristics can be used to help mitigate the occurrence and effects of stick-slip. High blade counts and smaller cutter size, which both result in a high number of points of contact with the formation, can decrease overall reactive torque as well as providing higher diamond volume to extend bit life.

Features referred to as Managed Depth of Cut (MDOC), Limited Depth of Cut (LDOC) (Mensa et al), and load limiters, among other names, serve to prevent over-engagement of the cutters on a PDC drill bit, thereby lessening the incidence or severity of stick-slip.

Cutter backrake is described as the degree of angle between the cutter axis and the cutter/rock interface. Higher backrake angles are better suited to withstand the impact associated with stick-slip and are employed to extend bit life.

All of the drill bit features mentioned above serve to both manage DOC, thereby mitigating stick-slip, and increase bit durability, thereby extending bit life. While these features can be successful in one or both of these purposes, they can detract from overall drilling efficiency and substantially reduce potential penetration rate. Figure 5 is an example of a PDC drill bit designed with many of these features.

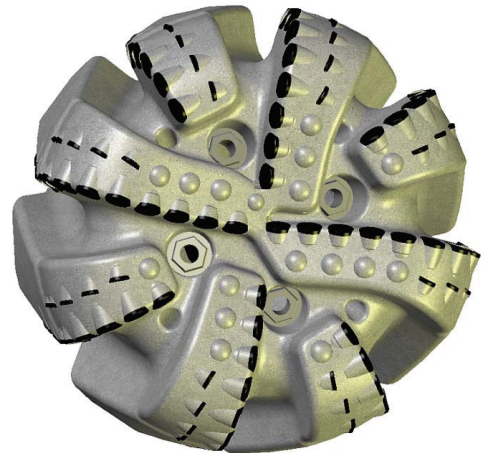


Figure 5. A heavy-set PDC bit with DOC control features.

In many instances where stick-slip is an issue the operator or driller may choose to employ a roller cone bit, which uses crushing and scraping actions to fail the formation as opposed to the shearing action of a PDC bit. The torque generated with a roller cone bit is very low as compared to a PDC bit, so while the bit-related stick-slip is almost completely eliminated the cutting action of the roller cone is much less efficient than a PDC bit and therefore sacrifices potential ROP.

Operating Parameters

Drillers attempt to mitigate stick-slip through the use of operating parameters – rotary speed and WOB. When stick-

slip is an issue, the rotary speed is increased and WOB is decreased to lessen the depth of cut. Just as with the specific PDC bit features described above, while decreasing the DOC can help to mitigate stick-slip, varying the operating parameters in this fashion is detrimental to potential penetration rate.

Effect of Torsional Impact Hammer on Bit-Related Stick-Slip

Torsional Impact Hammer Operation

The torsional impact hammer was designed specifically to reduce bit-related stick-slip while drilling with a PDC bit. The tool is positioned directly above the PDC bit within the bottom-hole assembly, as displayed in Figure 6. It uses the hydraulic energy of the drilling fluid to power a hammer and anvil assembly. The anvil is connected directly to the drill bit, independent of the tool housing. As the hammer strikes the anvil, it imparts a rotational impact through the anvil to the drill bit, thus providing a high frequency torsional impact directly to the cutter-rock interface. In this way the tool provides additional torsional energy outside of that provided by surface or downhole drives to assist in failing the formation.

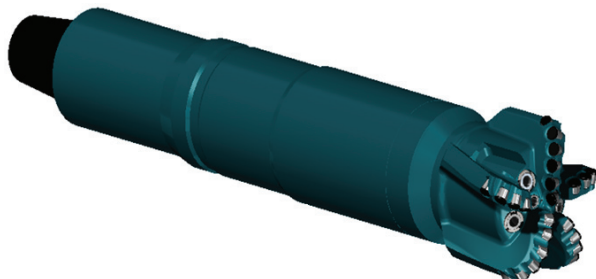


Figure 6. Torsional impact hammer and PDC bit.

Effect on Drilling Dynamics

The torsional impact hammer can greatly improve drilling efficiency by imparting a rapid impact to the cutter-rock interface. The rapid impact can effectively remove the reactive torque spikes seen in stick-slip mode, and raise the torque threshold at which the stick-slip mode is encountered.

While eliminating stick-slip alone will greatly improve efficiency and thereby boost penetration rate and improve bit life, one of the major advantages of using the tool is the ability to run an aggressive bit – one which was not designed with the aforementioned features to mitigate stick-slip and extend bit life. A more efficient PDC bit can greatly improve penetration rate over bits with higher cutter counts, higher cutter backrake angles, and DOC control features.

Case Study

One case where the torsional impact hammer was extremely successful in eliminating stick-slip and improving drilling performance comes from western Oklahoma. An operator was drilling 8.5" (216mm) production hole on a 21,000 ft (6,400m) deep Springer test well. The operator was

having difficulty developing an acceptable penetration rate as well as acceptable bit life. Trip times from this great depth combined with costs for directional services, fluids, measurement services, and overall drilling costs added up to staggering cost per foot through the interval. A variety of 6- and 7-blade, 5/8" (16mm) cutter PDC and IADC code 537-617 roller cone bits had been run through the interval on different steering tools.

While penetration rates and bit life were largely poor, the formations drilled largely have relatively low unconfined compressive strength. The massive column of high-density drilling fluid in the wellbore made the shales and sands difficult to shear with a PDC bit and crush with an insert bit, and the long drill string both lost energy due to vibration and was able to store a large amount of torsional energy when in stick-slip phase.

After an evaluation of the previous offset wells was made, the torsional impact hammer was chosen to assist in drilling the interval. An aggressive 5-blade, 1/2" (13mm) cutter PDC bit was chosen to run on the torsional hammer below a motor-assist rotary steerable system (RSS). The resulting run far exceeded expectations, drilling 1,823 ft (556m) at an overall penetration rate of 15.4 ft/hr (4.7 m/hr), by far the longest and fastest run through the interval to date. The assembly was tripped to examine the torsional hammer after 118 hours at 16+ ppg mud weight – conditions which had not been attempted before and the effects of which were not known. The PDC bit was in excellent condition (see Figure 7), with only one slightly chipped cutter. Due to several heavy sandstone sections coming up in the well, a heavier but still aggressive 6-blade, 1/2" (13mm) cutter double-row PDC design was chosen for the next run on an identical assembly. This was an excellent run as well, displacing several offset bit runs at over double the penetration rate. After 598 ft (182m) at 11.7 ft/hr (3.6 m/hr), the assembly was tripped for penetration rate while drilling an abrasive sandstone (see Figure 8). Note the smooth wear flats typical of stable cutter wear.



Figure 7. 5-blade, 13mm-cutter PDC bit following the run on the torsional impact hammer.

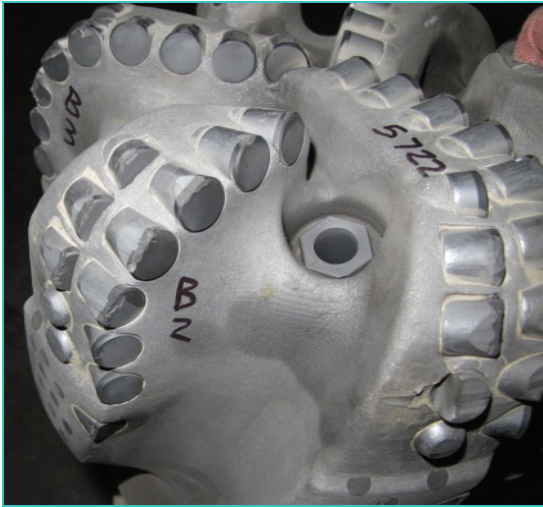


Figure 8. 6-blade, 13-mm cutter double-row PDC bit following the run on the torsional impact hammer.

Figure 9 shows a days-vs.-depth (DVD) chart of the test well where the torsional impact hammer was utilized versus the offset wells. Overall the two runs with the torsional impact hammer and aggressive PDC bits saved an average of four trips and 12 days on the well versus offset wells; this along with the large increase in penetration rate resulted in a section cost of \$214/ft (\$702/m) drilled – a \$315/ft (\$1033/m) savings on average over the offsets and a total estimated savings of \$763,000 for the operator.

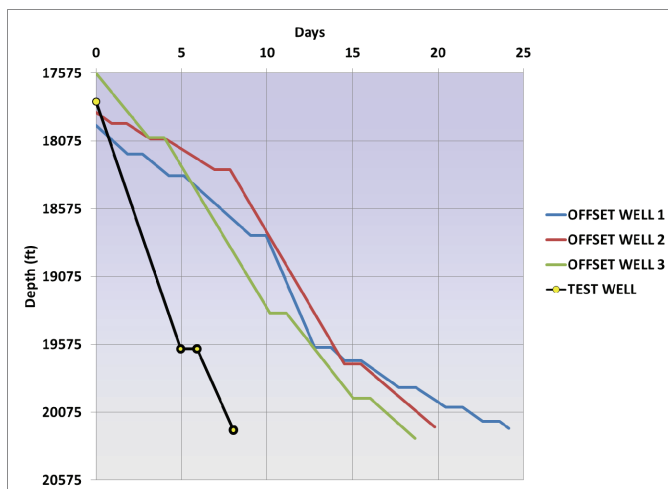


Figure 9. PDC bit runs on the torsional impact hammer versus offset bit runs at the same depths.

Conclusions

The conclusions reached in this paper are thus:

1. Stick-slip is an issue seen in many drilling environments that can be severely detrimental to drilling efficiency and equipment.
2. Bit selection and features as well as operating

parameters are used in an attempt to eliminate stick-slip but these methods can sacrifice drilling performance.

3. The use of a torsional impact hammer which imparts a rapid torsional impact to the PDC drill bit can be effective in reducing or eliminating the incidence and severity of stick-slip, improving overall drilling efficiency and allowing the practical selection of more efficient PDC bit designs.

Acknowledgments

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Nomenclature

- BHA* = Bottom-hole assembly
PDC = Polycrystalline Diamond Compact
DOC = Depth of cut
WOB = Weight on bit
ROP = Rate of penetration (or penetration rate)
MWD = Measurement-While-Drilling
LWD = Logging-While-Drilling
UCS = Unconfined Compressive Strength
ppg = pounds per gallon
lb = pound (measure of force or weight)
klb = kilo-pound (1000 pounds)
gal = gallon (measure of volume)
ft = foot (measure of distance)
hr = hour (measure of time)
RSS = rotary steerable system
PDM = positive displacement (mud) motor
DVD = days versus depth
IADC = International Association of Drilling Contractors

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