Journal of Sound and Vibration 417 (2018) 97–109

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

# Investigation of PDC bit failure base on stick-slip vibration analysis of drilling string system plus drill bit

Zhiqiang Huang [a], Dou Xie [a, *], Bing Xie [b], Wenlin Zhang [a], Fuxiao Zhang [a], Lei He [a]

[a] Electromechanical Engineering College, Southwest Petroleum University, Chengdu, Sichuan 610500, PR China
[b] Architecture and Realty Department, Sichuan Modern Vocational College, Chengdu, Sichuan 610207, PR China

ARTICLE INFO

*Article history:*
Received 25 July 2017
Received in revised form 31 October 2017
Accepted 29 November 2017

*Keywords:*
PDC bit failure
Stick-slip vibration
Torsional model
Torsional impact
Field experiment

ABSTRACT

The undesired stick-slip vibration is the main source of PDC bit failure, such as tooth fracture and tooth loss. So, the study of PDC bit failure base on stick-slip vibration analysis is crucial to prolonging the service life of PDC bit and improving ROP (rate of penetration). For this purpose, a piecewise-smooth torsional model with 4-DOF (degree of freedom) of drilling string system plus PDC bit is proposed to simulate non-impact drilling. In this model, both the friction and cutting behaviors of PDC bit are innovatively introduced. The results reveal that PDC bit is easier to fail than other drilling tools due to the severer stick-slip vibration. Moreover, reducing WOB (weight on bit) and improving driving torque can effectively mitigate the stick-slip vibration of PDC bit. Therefore, PDC bit failure can be alleviated by optimizing drilling parameters. In addition, a new 4-DOF torsional model is established to simulate torsional impact drilling and the effect of torsional impact on PDC bit's stick-slip vibration is analyzed by use of an engineering example. It can be concluded that torsional impact can mitigate stick-slip vibration, prolonging the service life of PDC bit and improving drilling efficiency, which is consistent with the field experiment results.


## 1. Introduction

PDC (Polycrystalline Diamond Compact) bit is the dominant bit-type utilized in oil and gas well drilling today, and its wide application has brought about great economic benefits [1,2]. Nevertheless, PDC bit drilling in hard formation has caused serious cutting tooth failure, such as tooth fracture and tooth loss, as shown in Fig. 1, which will greatly reduce rate of penetration (ROP) and increase drilling cost [3,4]. Previous studies have indicated that the undesired stick-slip vibration is the main source of PDC bit failure [5].

As shown in Fig. 2 [6], the stick-slip vibration of PDC bit is featured by repeated alternation of stick phases where the bit remains still and slip phases where the bit accelerates to several times higher than rotary table speed [7]. In the slip phases, PDC bit sustains great impact loads due to the high velocity impact with borehole wall and downhole, which will accelerate PDC bit failure.

* Corresponding author. State Key Laboratory of Oil & Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu, Sichuan 610500, PR China.
*E-mail address:* xied_swpu@foxmail.com (D. Xie).

https://doi.org/10.1016/j.jsv.2017.11.053
0022-460X/

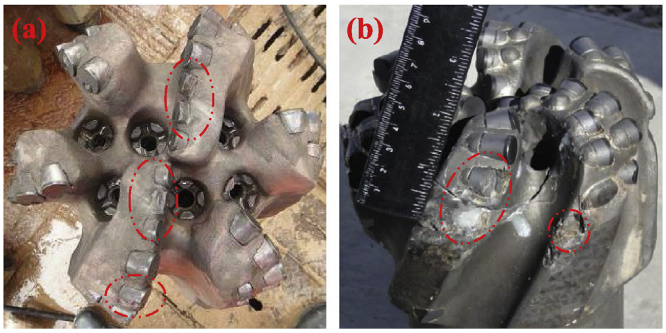


**Fig. 1.** Failure photographs of PDC bit. (a) tooth fracture, (b) tooth loss.

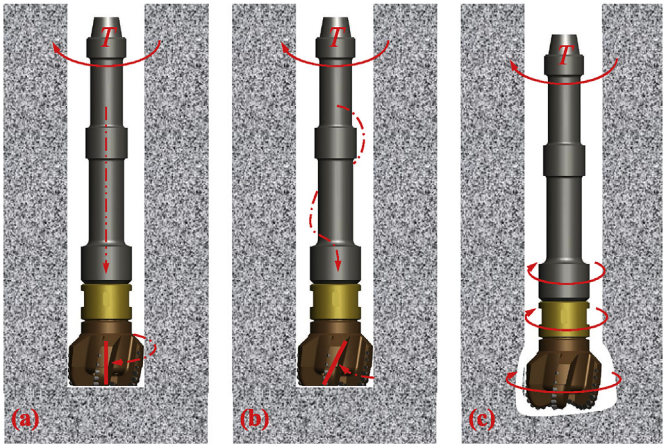


**Fig. 2.** Stick-slip in a drilling environment. (a) stick phase, (b) drilling string distortion, and (c) slip phase.

A number of research efforts about the stick-slip vibrations of drilling tools have been carried out, and the main research methods include theoretical analysis, experimental study and computer simulation [8]. The key to theoretical analysis is establishing a reasonable dynamical model, and lumped-parameter models have been proposed to keep a simpler analysis. For instance, Lin, Rudat and Omojuwa et al. [9–11] investigated the torsional vibration responses of drilling string by the torsion pendulum model of 1 DOF, and proposed the methods of reducing stick-slip vibration by optimizing drilling parameters and increasing viscous damping. Brett, Jansen, Richard and Kovalyshen et al. [12–15] established a 2-DOF lumped-parameter torsion pendulum model to study the stick-slip vibration of drilling string, and analyzed the effects of viscous damping coefficient and the length of drilling string on stick-slip vibration. Navarro-López and Eva et al. [16–18] considered drilling string as a piecewise-smooth model with multi-DOF, and proposed the sliding-mode control method to reduce stick-slip vibration. In the experimental aspect, the downhole measuring techniques are used to monitor stick-slip vibration in the field tests, but the measurement data doesn't necessarily pinpoint the root cause of drilling dysfunction due to its low-frequency and the complexity of drilling [19]. On the other hand, the laboratory tests were carried out by simplifying the drilling system and building reasonable experiment devices to explore the producing mechanism and the influence factors of stick-slip vibration [20–23]. Moreover, with the development of computer technology, Zhu and Kapitaniak et al. [24,25] studied the stick-slip vibrations of drilling tools using finite element method, reducing the research period and costs greatly compared with experimental work. Among the above three kinds of methods, the most essential one is the theoretical analysis. However, the previous theoretical studies usually treat drilling string as a model with 1 or 2 DOF, using which to study the complex dynamics of the drilling string system could lead to inaccurate predictions [26], and the mechanical properties of PDC bit breaking rock are ignored in the few multi-DOF models. The ordering relationship between PDC bit failure and stick-slip vibration has not yet been reported. There are few references available to the theoretical study of torsional impact drilling [27].

In this paper, the stick-slip vibration of PDC bit is studied by establishing a piecewise-smooth torsional model with 4-DOF of drilling string plus drill bit to simulate non-impact drilling. In this torsional model, PDC bit's friction and cutting behaviors are comprehensively considered. PDC bit failure caused by stick-slip vibration and the effects of drilling parameters are discussed. A new 4-DOF torsional model is developed to study the effect of torsional impact on PDC bit's stick-slip vibration. A field experiment is carried out to supplement the theoretical analysis. The research results will assist engineers to optimize