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# Analysis of reamer failure based on vibration analysis of the rock breaking in horizontal directional drilling

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ABSTRACT

In horizontal directional drilling (HHD), the reamer drilling in soft and hard sandwiching has occurred the excessive wear, broken cutting teeth, swapped cone and even catastrophic buried wells accidents and other engineering problems. This paper involves elastic–plastic mechanics and rock mechanics, using the Drucker–Prager criterion as the rock constitutive relation and the plastic strain as a failure criterion of rock broken. And it establishes a nonlinear dynamics finite element model which is composed of a diameter of 601 mm cone reamer entity and a three-dimensional rock by the finite element method. The goal of the paper is for a comparative study of the reamer's lateral, axial and torsional vibration intensity in the former soft–hard formation and former hard–soft formation and homogeneous formation. And it still studies the influence of the construction parameters for the reamer's vibrations characteristics in the soft and hard sandwiching. The study results show that the severe lateral vibration of the reamer is the root cause of the reamer's premature failure, the adverse effects of which are much larger than the axial vibration and torsional vibration on the reamer's premature failure. And the unreasonable reaming parameters exacerbate the lateral vibration. In addition, the reamer's lateral vibration intensity in the former soft–hard formation and former hard–soft formation reaches a homogeneous formation several times the original magnitude. Especially in the former hard–soft formation, the lateral vibration amplitude peak, acceleration peak and acceleration RMS respectively achieve the homogeneous formations of 4.2 times, 6.6 times, 7.1 times. This paper is based on the baker Hughes BHA vibration grading standards, which recommend the optimum construction parameters in soft and hard sandwiching, and the field application case demonstrates the correctness of the recommendation. The study conclusions provide a scientific basis for the preferable construction parameters, which has an important significance for slowing down the reamer's quick failure, and improving work safety when the reamer drills in soft and hard sandwiching.



## 1. Introduction

Energy related to a national economic development is an important strategic resource, and ensuring energy security is very important. Chinese oil and gas resources are unevenly distributed; in 2012 foreign energy dependence reached 57.4%, and 90% of oil imports are dependent on maritime transport. Faced with the increasingly sophisticated, East China Sea issue, the laying of pipeline conducting the west–east gas transmitting project, and transporting the energy from abroad to the inland (such as the Myanmar pipeline) to share the risk is very necessary. Currently, China's total pipeline length is

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about 80,000–100,000 km, and by the end of the 12th five-year plan in 2020 it is expected to reach 150,000–200,000 km. while the United States has only constructed 300,000 km, thus China's domestic oil and gas pipeline laying project is very large in magnitude. Horizontal directional drilling is a key technology of pipelines, and currently plays an increasingly important role. The key technology involves many technical problems which must be solved, and if these technical problems are not resolved, it will affect the construction quality and efficiency. More and more soft and hard sandwiching must be drilled in the construction process, and bit failure is very serious in soft and hard sandwiching. For example, in certain horizontal directional drilling engineering projects of the West–East Gas Transmission Pipeline Project Extension of the Dao shui River, due to the presence of a wide range of soft and hard sandwiching, the reamer wears down severely and cutting teeth are broken, as shown in Fig. 1 [1]. Not only does bit failure result in the increasing use of bits, but also it delays the construction period, significantly extending the duration of the delay, even causing borehole instability, resulting in a catastrophic buried well accident. The problem of bit failure in soft and hard sandwiching has become one of the problems restraining the construction quality and efficiency in horizontal directional drilling. Currently, the problem of bit failure in soft and hard sandwiching is not clear, and experts have yet to find a way to deal with the problem, as the relevant research literature is rare, thus research regarding reamer failure in soft and hard sandwiching is very necessary.

For a long period of time, the horizontal directional drilling technical processes and BHA's system research level have remained in the reference oil and gas drilling and geological drilling process stage. While the rock of oil drilling is usually several km deep, the rock of the horizontal directional drilling is typically several tens of m deep, and the stress states of both contain large gaps. Thus problems involving horizontal directional drilling technology promotion begin to become increasingly prominent. The basic theory is seriously lagging behind in terms of technology demand, and if this situation persists, it will severely restrict horizontal directional drilling application and development.

BHA vibration has a great impact on work safety. Domestic and foreign scholars have carried out extensive research concerning BHA vibration. Langeveld and Shell Research bV [2] studied PDC bits in the fight against hard formations, which they found was due to vibration caused by the BHA failure, and pointed that the lateral vibration was the main cause of bit wear and tooth damage. Zhu et al. [3] researched the drilling failure issues in the horizontal directional drilling, and pointed out that insufficient make-up torque was the main predisposition factor and bending moment generated by the drill pipes hanging were the immediate causes of the failure accidents. Jafari et al. [4] found that the lateral vibration and axial vibration were the main causes of failure of the BHA, and that the reasonable control of the revolutions per minute (RPM) and weight on bit (WOB) could effectively reduce the vibration of the bottom hole. Dykstra et al. [5] performed an experimental study on the drill bit and drill string dynamics, and pointed out that the lateral vibration for the BHA was much greater than the adverse effects of axial vibration, and due to the differences among the WOB, RPM and rock properties, the BHA lateral acceleration would generally be more than 20 g, with the maximum reaching as high as 200 g. Christoforou and Yigit [6] found that the interaction among axial vibration, lateral vibration, torsional vibration led to failure of the bottom hole, and that adjusting the construction parameters could slow down the adverse effects of vibration on drilling. Perry [7] noted that bit trend was not only caused by the impact of the bit's cutting cross-section, but also by the impact of the operating parameters, such as WOB and RPM. Deng and Gu [8] pointed out that controlling the shield tunneling parameters can minimize security risks in the former soft–hard formation, and greatly improve the efficiency of shield tunneling. Liu et al. [9], using cone drill geometry, kinematics and a static drill rock interaction model, and based on a simplified drilling process, established a dynamic axial cone bit model, drill lateral momentum mathematical model, and drill torsional vibration model.

However, for research specifically regarding BHA failure due to the BHA vibration and vibration-induced rock reaming in horizontal directional drilling are almost non-existent. In addition, the actual situation for the vibration characteristics of breaking rock in horizontal directional drilling is also non-existent, especially research regarding soft and hard sandwiching. In this paper, the reamer's vibration is analyzed based on elastic–plastic and rock mechanics, and using the Drucker–Prager criterion as the rock constitutive relation and plastic strain as a failure criterion of broken rock. And it makes a comparative study of the reamer's lateral, axial and torsional vibration intensities in the former soft–hard formation (the former formation is located close to the reamer), former hard–soft formation and homogeneous formation, thereby determining that the

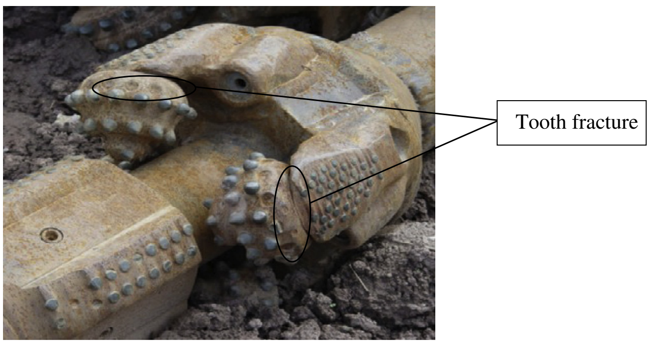


**Fig. 1.** Reamer tooth wear and fracture figure.