FEA of BTA Deep Hole Drilling Based on ANSYS

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Abstract. This paper takes BTA deep hole drilling as the research object. ANSYS software is used in the static and dynamic analysis of the force of BTA deep hole drilling process from theory and in modeling and simulation. Firstly, According to the finite element analysis, the most concentrated stress and the largest deformation of the cutting tool are the cutting edge and the cutting surface of the tool block. The main vibration of drill stem is in the form of twist and bending. Secondly, it is concluded that the main vibration of drill stem is in the form of twist and bending through the modal analysis. Finally, the natural frequency of this type of BTA drill stem is obtained by analyzing the amplitude response curve, and it is suggested to avoid the rotational speed near the dangerous speed during machining to avoid resonance of the drill stem.

Keywords: BTA deep hole drilling; ANSYS; FEA; inner-chip removal

1. Introduction
Deep hole drilling processes, which differ significantly from conventional drilling processes, are relevant for a lot of different applications where holes with high length-to-diameter-ratios and very good qualities are necessary[1]. Deep hole drilling usually adopts two processing methods: inner-chip removal processing and outside-chip removal processing. The main form of inner-chip removal is BTA deep hole drilling[2]. The working principle is that during deep hole drilling, the cutting fluid enters the cutting zone from the outside of the drill stem and the annular space formed by the processed hole, and the chips are removed from the inside of the drill stem, as shown in Fig. 1.

![Figure 1. BTA deep hole drilling](image)

When drilling deep holes with BTA form, there are two types of commonly used drill tool structures: single-blade BTA deep hole drill and multi-blade staggered teeth BTA deep hole drill[3]. However, deep hole drilling technology currently presents certain difficulties at the technical level. For example, the overall rigidity of the drilling system is relatively poor, the chip exit is blocked, the drilling is
unstable, vibration occurs, the tool wear and breaking[4]. By the use of the finite element method, the analytical modeling method and the experimental method[5-7]. The numerical approaches used finite element analysis (FEA) to simulate the machining process. Li made use of Deform-3D finite element analysis software to simulate the single-ended near-dry BTA drilling, and analyzed the distributed situation of cutting force, cutting temperature and tool wear in different cutting parameters[8]. Wei analyzed the thermal stress and transient dynamics of common bit, solved the optimization problem of cutting parameters before machining, improved the machining efficiency and saved the cost[9]. Dong Built a three-dimensional model of BTA deep hole drilling, simulation the static characteristic of the three-dimensional model using Ansys simulation software, observed the wear condition of the BTA drilling teeth, middle teeth and side teeth in the Experiment, verify the results of simulation, providing a basis for the BTA drilling structural optimization[10]. At present, the existing research focuses on the simulation of turning and milling tools. There are few researches on cutting tools of deep hole machining, especially the inner chip removal cutting tools of BTA system.

In this paper, the single-edged BTA deep hole drill is taken as the research object. The cutting part of the drill bit is mainly composed of an inner edge, an outer edge, a drill tip, a guide block and a clearance hole. Two guide blocks are arranged on the circumference of the drill bit, and the cutting edge is generally ground with two or more chip steps, as shown in Fig. 2. Generally only suitable for deep hole drilling of small and medium diameter. It is suitable for a range of 6 to 65 mm, the aspect ratio can be up to 100, and maximum up to 250.

2. Analysis and Simulation of Static for BTA Deep Hole Drilling

Static analysis refers to the change of structural stress and strain of the BTA tool structure under the condition of stable load, without considering the tool is subject to varying loads or changes over time. In the analysis, it is assumed that the material, structure and state of the BTA tool are linear, and the entire model load and deformation are linear variation.

2.1. Establishment and Import of Finite Element Model for BTA Deep Hole Drilling

Modeling was constructed using UG software based on the boundary dimension of the BTA deep hole drill. Create a new static structure static analysis project in ANSYS software, import the created 3D model into ANSYS software, and generate geometry.

2.2. Enter Material Properties in the Material Library

After importing the model of the BTA deep hole drill tool, the basic characteristics of the material of the tool structure are defined, including the unit system, the unit type, the unit constant, the elastic modulus of material, the Poisson's ratio, the density and the use of material library files, etc. In this paper, the Linear Elastic Isotropic model is used to define material properties as isotropic. In order to simplify the mesh size in the finite element meshing and reduce the amount of computation in the solution, the model is simplified, and the key dimensions are retained. Meanwhile, the connection of the thread and the welding of the blade are neglected. The new material (40Cr) of the cutter body is added to the material library, where the material density is $7.9 \times 10^3$ Kg/cm$^3$, the elastic modulus is 210 GPa and the Poisson's ratio is 0.3. The material for the blade and the guide block that added is YG8, the density is $14.5 \times 10^3$ Kg/cm$^3$, the elastic modulus is 540 GPa and the Poisson's ratio is 0.3, etc. Workpiece material is TC4 titanium alloy, its diameter is 56mm, the processing aperture is 34mm, and
the length is 1995 mm.

2.3. Mesh Generation
Mesh Generation is an important step in finite element analysis. The finer the mesh is, the more accurate the simulation results. Based on the automatic division of ANSYS software, the mesh density is increased for the parts where the force is concentrated, such as the tip of the knife, the corner, and the guide block, so as to increase the accuracy of the simulation. For other parts with relatively complete structure and large size, a sparse mesh division is adopted to reduce the amount of calculation, as shown in Fig. 3. The size of the important structural part is 0.3 mm, the other part is 1 mm.

![Mesh generation and optimization of BTA drill tool](image)

**Figure 3.** Mesh generation and optimization of BTA drill tool

2.4. Applying Loads and Defining Constraints
According to the above mechanics model analysis of BTA drill tool, the model in ANSYS is loaded. The fixed constraint conditions are cutter body and guide block. The position where apply the force load is the blade, as shown in Fig. 4.

![Axial load and radial load Diagram of BTA tool](image)

(a) Axial load Diagram of BTA tool  (b) Radial load Diagram of BTA tool

**Figure 4.** Axial load and radial load Diagram of BTA tool

Add Stress and Strain in the Solution solver toolbar. And then, solve the Solve Command. The stress and strain calculated by ANSYS12.0 software are expressed in the form of cloud picture respectively. The position of stress concentration, the maximum stress point and the structure with the largest deformation can be seen intuitively. Fig. 5 shows that the stress and strain cloud diagram is divided into two parts: the cutting edge and the cutting surface of the tool block.
3. Analysis and Simulation of Dynamic Characteristics for BTA Deep Hole Drill

3.1. Modal Analysis

It is possible to analyze the main modal characteristics of the drill stem when it is subjected to a certain range of frequencies more directly by modal analysis, and then the actual vibration response of the drill stem under the action of the vibration source can be obtained. The dynamic characteristics of the drilling system can be evaluated, the structural dynamic characteristics of the newly designed members can be estimated and optimized, the failure of the system can be diagnosed and predicted, and the load of the drill stem system can be identified.

From the vibration dynamics, it can be seen that most of the energy of vibration is concentrated in the first ten-orders. Therefore, it is generally only necessary to analyze the modal deformation nephograms of the first order to the tenth order. As shown in Fig. 6, the first ten modal shapes of drill stem are calculated through the modal analysis, it is concluded that the main vibration of drill stem is in the form of twist and bending.
3.2. Harmonic Response Analysis

Harmonic response is used to analyze the cyclical response of the drill stem under cyclic loading. During the analysis, only the steady-state forced vibration of the drill stem is calculated. The purpose of the analysis is to obtain the curve of the displacement and frequency of the drill stem at different frequencies, so as to determine the sustained dynamic characteristics of the drill stem, thereby avoiding resonance, fatigue and other results from forced vibration. Fig. 7 shows that the results of the harmonic response analysis. It can be seen that when the frequency is 300HZ, the amplitude in the X direction reaches the maximum, and the drill stem may produce resonance at this frequency.

Due to the harmonic response analysis of the drill stem based on the modal analysis, the frequency range is between 0-70 Hz and the load is applied to the part of drill tool, as shown in Fig. 8. The frequency at which the amplitude reaches the peak is consistent with the modal frequencies from the first to tenth order of the excitation frequency and it is also the natural frequency of the drill stem. In the process of deep hole drilling, the external excitation frequency should be controlled to avoid resonance, which can reduce the influence of vibration on the processing quality.
4. Conclusion

By using ANSYS finite element analysis software, the statics and dynamics of BTA deep hole drilling process are analyzed theoretically and on the level of modeling and simulation, and the following conclusions can be drawn:

1. The most concentrated stress and the largest deformation are the blade parts. Since the cross section of the BTA bit is a complete annular structure, the structural integrity of the drill tool is greatly enhanced. The torque is larger and the deformation is smaller than the gun drill.

2. Through the ANSYS simulation analysis, the stress cloud diagram of the bit is solved, which provides the basis and data support for improving the size structure of the bit.

3. If the external excitation frequency is close to a certain order value, the drill stem will resonate and the amplitude will increase significantly, which will affect the processing quality. In order to reduce the influence of vibration on the processing quality, the external excitation frequency should be controlled to avoid resonance. Or by optimizing the design of drill stem, the amplitude can be reduced by changing the frequency range of drill stem and staggering the excitation frequency. According to the results of the modal analysis above, torsion and bending are the main vibration forms of drill stem.

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