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Kinematical Simulation and FEA on Hydraulic Drill Machine Applied on Underground of Coal Mine

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Abstract

In order to find out the essence of sticking for drilling rod applied on underground of coal mine under geological condition of gas outburst, 3D model for a kind of hydraulic drill machine is built, and the kinematical simulation for it is done to test the validity of its 3D model. Besides, finite element analysis for drilling rod used in the drill machine is accomplished simulating geological condition of gas outburst and other actual working conditions, finally the results show that sticking for drilling rod likely happens in the middle of the drilling rod.

Keywords: *coal mine, drill machine, finite element analysis, gas outburst, sticking*

1. Introduction

Gas outburst is dangerous for coal mining, so many effective attempts are taken to eliminate gas outburst, *e.g.*, some drill machines are applied to drill holes towards the coal wall containing gas on the underground of coal mine, which is called as gas releasing with drilling holes [1-3]. However the current drill machines cannot meet all the requirements for releasing gas inside coal seam, which leads to sticking, even cracking for drilling rod during the process of drilling holes. Furthermore gas explosion due to cracking for drilling rod likely happens, and that is regarded as significant mining disaster [4, 5]. Therefore a drill machine driven by hydraulic power is designed according to the conditions on the underground of coal mine, and kinematical simulation for the whole drill machine is done to verify the validity of the model, finally finite element analysis (abbr. FEA) is done to analyze the essence of sticking for drilling rod based on the 3D model and kinematical simulation.

The following sections are as follows: firstly, the whole structure of drill machine is designed. Secondly, all the parts are modeled according to 3D modeling approach, and the whole drill machine is assembled. Next kinematical simulation for the whole drill machine is done. Finally FEA is done to analyze the essence of sticking.

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2. Structure of Drill Machine

Drill machine is designed according to the actual conditions on the underground of coal mine and the requirements of drilling holes, so the overall structural framework is built as follows: firstly, post drill type of skeleton is applied for supporting the whole drill machine. Secondly, drilling rod is driven by a hydraulic motor via a reduction gearbox to rotate positively. Besides, rotation mechanism is driven by a hydraulic cylinder to feed into the coal wall. The whole drill machine is powered by hydraulic system, and the control panel is separated with the main body of drill machine in order to keep enough distance between the holes drilled and the operator.

2.1. Skeleton

Post drill type of skeleton is widely applied among the current drill machines due to its simple composition, convenient assembling and disassembling, and angle of drilling holes adjustment [6-7].

When it works, it supports up to the roof and down to the underground of coal mine tunnel simultaneously, so that the whole drill machine is held in the space of coal mine tunnel steadily, meanwhile the entity cannot move with the action of reactive forces. Then it adjusts the angle of drilling holes including horizontal and vertical angles in order to fit the accurate location of drilling hole.

2.2. Rotation Mechanism

Rotation mechanism is an essential component of drill machine, which provides the drilling rod with torque and drives to rotate positively, and the driving force derives from hydraulic system.

The rotation mechanism consists of hydraulic motor, reduction gearbox and holder. Among that, the hydraulic motor provides with low torque and high rotation speed under the driving force of hydraulic power, then it transmits the torque and motion to two levels of reduction gearbox in order to obtain high torque and low rotation speed [8], finally the driving force is output to drilling rod via the holder connected with the output shaft of gearbox, and the holder is used for griping the drilling rod to rotate together synchronously when the hydraulic motor works.

2.3. Feeding Mechanism

The feeding mechanism provides with the push and pull force to rotation mechanism when it drills holes, and the force derives from a hydraulic cylinder. The drilling rod and rotation mechanism move along the guide rail under the action of push and pull force from piston rod.

2.4. Power System

The whole drill machine is powered by hydraulic system, and the hydraulic pump applied is a kind of variable displacement piston pump, thus the flow rate varies following amounts of the loads uploaded [9, 10].

2.5. Basic Parameters

According to the above overall design, the framework of drill machine is built, and its structure and performance parameters are shown in Table 1.

Table 1. Basic Parameters of Drill Machine

items /unit	torque /N.m	rotation speed /r/min	diameter of drilling rod /mm	max feeding force /kN	displacement of pump /ml/r
drill machine	2000	50	73	70	0-53

items /unit	output pump pressure /MPa	transmission ratio of reduction gearbox	angle of drilling holes /°	dimension /m*m*m
drill machine	20	35	-90-+90	2000*800*1500

3. Modeling for Drill Machine

There are many modeling ways, *e.g*., top to down or down to top, meanwhile there are many modeling tools such as Pro/E, UG, Catia and Solidworks [11, 12]. As a kind of special equipment applied on the underground of coal mine, drill machine has complex structure and special components, thus it is modeled according to the category and the structure of every component, which is shown in Figure 1.

3.1. Modeling for Skeleton

The skeleton is used for supporting the whole machine, and available of adjusting the angle of drilling holes, which is shown in Figure 2. It consists of chassis labeled as 1, support rods labeled as 2 and 3, hydraulic cylinder labeled as 4 and guide rail labeled as 5.

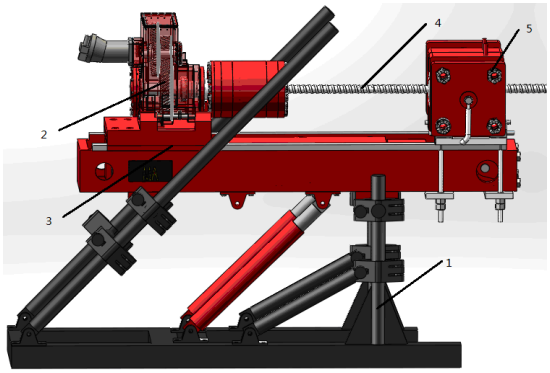
The skeleton is modeled according to the space dimension where drill machine works on underground of coal mine, *i.e*., length, width and height. Besides support rod and hydraulic cylinder for angle adjustment are mounted with the chassis, therefore the mechanical type of chassis is determined [13]. The range of piston rod of hydraulic cylinder is determined according to dip angle of drilling holes required. The guide rail is used for guiding feed movement of rotation mechanism on it.

When the drill machine works, the dip angle is adjusted and determined by regulating the extension length of piston rod labeled as 4, and the whole machine is fixed under the role of support rods labeled as 2 and 3.

3.2. Modeling for Rotation Mechanism

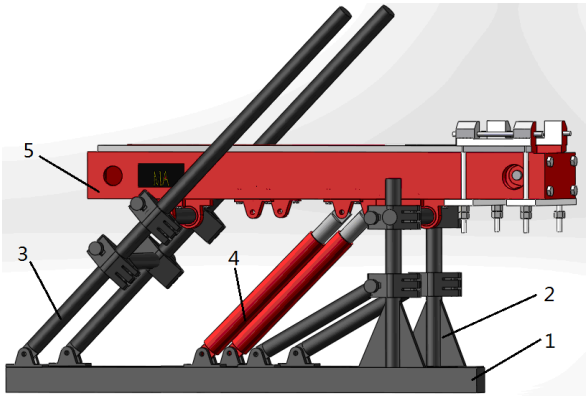
Rotation mechanism is a key component of the whole drill machine, for coal and rock are cut under the role of rotation movement, and it is modeled in Figure 3. It consists of hydraulic motor labeled as 1, reduction gearbox labeled as 2 and holder labeled as 3.

When the hydraulic motor driven by hydraulic pump rotates, high rotation speed and low torque are generated, then it transmits them to reduction gearbox via its output shaft. In order to gain high torque, the reduction gearbox adopts two levels of reduction speed helical gears, thus high torque and low rotation speed are obtained and transmitted to the holder. The holder is a normally open machine, *i.e*., it closes up and grips the drilling rod when it works [14], so that the drilling rod rotates with the holder simultaneously driven by the hydraulic motor.



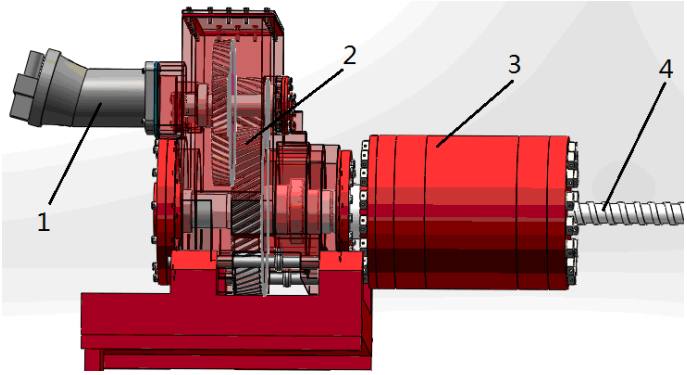
1-support mechanism 2-rotation mechanism 3-feeding mechanism 4-drilling rod 5-chuck

Figure 1. Overall Structure of Drill Machine



1-chassis 2-support rod 3-another support rod 4-hydraulic cylinder for angle adjustment 5-guide rail

Figure 2. Skeleton of Drill Machine



1-hydraulic motor 2-reduction gearbox 3-holder 4-drilling rod

Figure 3. Rotation Mechanism of Drill Machine

The feeding mechanism is mounted underneath the middle of the two columns of guide rail, and it consists of hydraulic cylinder and the corresponding auxiliaries. Among that, the hydraulic cylinder connected with the rotation mechanism is used for pushing and pulling the drilling rod, thus the rotation mechanism moves along the guide rail driven by the hydraulic cylinder, so that the drilling rod enters deeper coal wall.

4. Kinematical Simulation for Drill Machine

Kinematical simulation is a way to test the validity of the whole model and fits for components, so that interferences due to inconsequence of 3D model are rectified [15].

4.1. Kinematical Simulation for the Whole Machine

Kinematical simulation for drill machine is done according to the above 3D model, the setup parameters are shown in Table 2. The simulation is lasted for 30 seconds according to the feed and rotation speed, and 2 screenshots when the rotation mechanism is in initial position and terminal position of the guide rail are shown in Figure 4 (a) and (b) respectively. However the Figures are not clear due to too long drilling rod (100 meters).

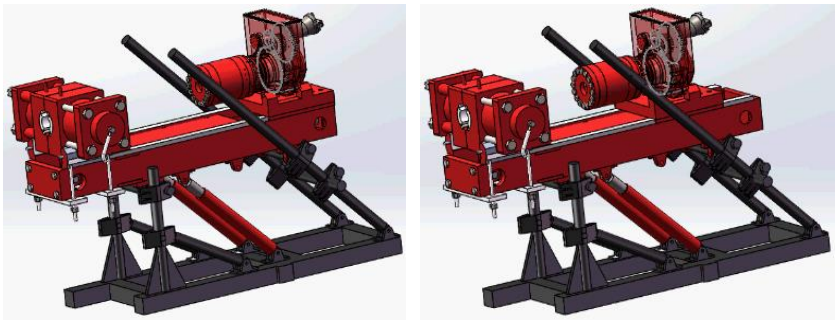
The result of simulation shows the dynamic kinematics relationship among all the structural components, and no global interference components arise.

Table 2. Parameters for Kinematical Simulation

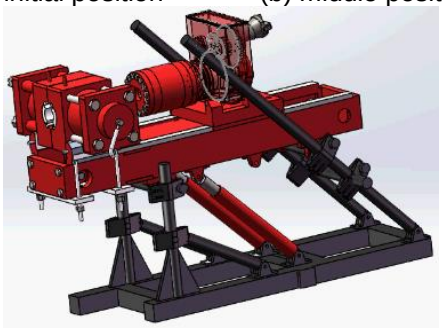
duration time /s	feeding speed /m/s	feeding force /kN	rotation speed /r/min
30	0.3	60	50

(a) initial position (b) terminal position

Figure 4. Kinematical Simulation for the Whole Machine



(a) initial position (b) middle position



(c) terminal position

Figure 5. Kinematical Simulation for Rotation Mechanism

4.2. Kinematical Simulation for Rotation Mechanism

Kinematical simulation for rotation mechanism without the drilling rod is done in order to verify the validity of model of rotation mechanism, and 3 screenshots when it is in initial position, middle position and terminal position are shown in Figure 5 (a), (b) and (c) respectively.

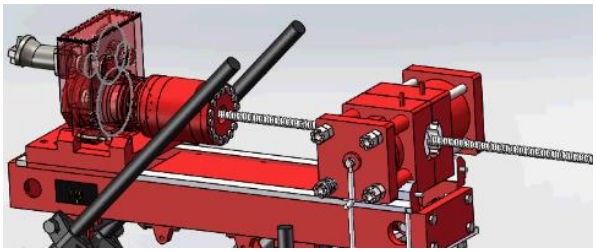
During the process of simulation, the rotation mechanism moves along the guide rail driven by the feeding hydraulic cylinder accompanying with the hydraulic motor and the holder rotate continuously.

4.3. Kinematical Simulation for Each Component

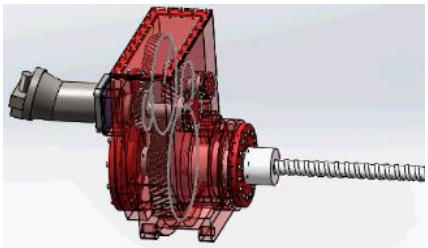
The models for the whole framework and the rotation mechanism are available according to the above results, then the model of sub-component is verified and the screenshots of kinematical simulation are shown in Figure 6.

Among that, a screenshot of the upper half of the whole machine is shown in Figure 6(a), then rotation mechanism with drilling rod is shown in Figure 6(b), finally rotation mechanism only is shown in Figure 6(c).

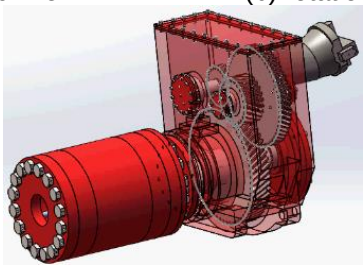
The results of simulation show that the whole machine and each component are modeled properly, thus the further analysis on the structure of the drilling machine can be done to solve the issue of sticking for drilling rod.



(a) the whole machine



(b) rotation mechanism with drilling rod



(c) rotation mechanism only

Figure 6. Kinematical Simulation for Each Component

5. Analysis on Sticking for Drilling Rod

Sticking for drilling rod is a complex problem happened on the underground of coal mine, and many factors lead to the occurrence of sticking[16,17]. Finite element analysis is adopted to study the deformation process of drilling rod in order to determine the exact position and essence of sticking [18, 19].

5.1. Setup Parameters

The analysis process simulates the actual process of drilling holes on the underground of coal mine, and some parameters must be loaded to analyze sticking for drilling rod, *e.g.*, forces imposed on the drilling rod and parameters about working conditions [20], which are shown in Table 3.

Among that, the torque from the rotation mechanism is imposed on the root of the drilling rod, the friction force is imposed on all the body through the drilling rod, and surface stress of coal mine is imposed on the terminal of drilling rod.

Besides, some parameters should be set up as precondition of analysis. Among that, the mesh is generated automatically, and dimension of mesh is set up as 100mm.

Table 3. Parameters Loaded for Analysis

torque /N.m	push force /kN	rotation speed /r/min	friction /N	surface stress of coal mine /MPa
2000	60	50	20	19

5.2. Result of Analysis

Result of analysis is got via preprocessing, calculation and solution, post-processing for drilling rod, *i.e.*, finite element modeling, mesh generation, calculation, solution, analyzing and processing on results, which is shown in Figure **7** according to the above parameters. Among that, Figure **7**(a)-(d) represent the different stages of deformation of drilling rod with different loads and magnitude respectively, however Figure **7**(e) represents the exact value of deformation of drilling rod corresponding to the last loads, *i.e.*, the maximum value among the experimental data.

Therefore, the result indicates the following issues:

Firstly, deformation of drilling rod varies as external forces exerted on it vary.

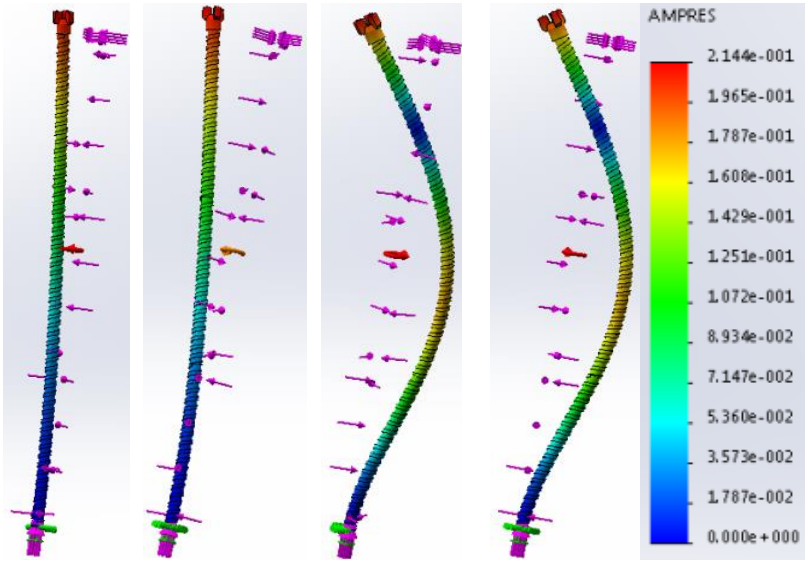
Secondly, the maximum load arises at the terminal of drilling rod, *i.e.*, drill bit, which is shown with red zone.

Thirdly, deformation of drilling rod becomes more and more serious as the frequency of vibration increases, and the maximum deformation arises in the middle of the body when the frequency of vibration reaches 33.454Hz.

6. Conclusion

In order to solve sticking for drilling rod, kinematical simulation for the whole drill machine based on its 3D model is done, and the result shows that the 3D model of drill machine is available and no interference is detected among mechanical structure of drill machine.

Besides, FEA on drilling rod is accomplished according to all the forces imposed on drilling rod and the working conditions, finally the following result is got: the terminal of drilling rod, *i.e.*, drill bit, is imposed with the maximum stress, and sticking for drilling rod likely happens in the middle of drilling rod under the current geological and working conditions.



(a) (b) (c) (d) (e)

Figure 7. Analysis on Sticking for Drilling Rod with FEA

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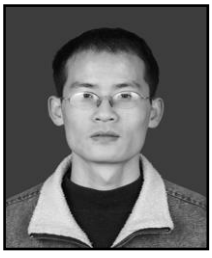

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