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Research Paper

USING COMPUTER SIMULATION TO AID THE RESERCH OF DRILLING PROCESSES

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Abstract

Drilling wells is one of the primary methods used for mineral exploration. Scientific studies have aimed at improving the technical and economic aspects of drilling because of the current competitive economic conditions. Note that the primary topic of these studies has been developing new effective rock-cutting tools. To design a new rock-cutting tool, a thorough, reliable, and accurate study of the processes that occur during drilling is necessary. During drilling, mechanical, hydraulic, thermal, and chemical phenomena, which are interdependent and affect the performance of a drilling tool, simultaneously occur; therefore, a systematic, integrated approach is required for studying drilling processes. Field-based and laboratory experiments are quite tedious to perform and require high material costs, and it is often not possible to separately evaluate small elements of the drilling model. Therefore, computer simulation is an important research tool that enables accurate and reliable visualization of even small parts of the model. **The aim.** The aim of this study is to examine the potential for computer simulation of the processes that occur during drilling. **Objective**. In this study, we evaluated the simulation features of various software products, such as KOMPAS-3D, ANSYS, Delphi, and LabVIEW, for their utility in studying the processes that occur during drilling. The possibility of computer simulation for studying drilling processes, including its advantages and disadvantages, are demonstrated. The results are obtained from a model that simulates a rock cutting tool. The main uses of the rock cutting tool are outlined, and the drilling simulation development is planned. **Choice of research method.** The study of the capabilities of existing modern software products, for use in drilling process research, is carried out by an analytical review method.

Keywords: computer simulation, cutting, rock, computer technologies, drilling, software.

1. Introduction

Drilling is a method that is primarily used by the mining industry for mineral exploration. In an era of economic challenges and limited energy resources, exploration drilling is an important aspect for the development of the global economy. Modern drilling requires adherence to high technical standards along with beneficial economic indicators. Drilling requires the integrated approach in the scientific drilling processes study. Note that a drilling model is a complex system that considers the mechanical, chemical, hydraulic, and thermal states. Certain drilling elements need to be examined at the micro level to achieve reliable results [1, 2]; therefore, studying drilling-related processes is a difficult task. Solving this models with standardized methods is not always possible; therefore, for this research, computer simulation is the most promising tool, and it is capable of

1) optimizing the research model to match the real conditions,
2) reducing tool development time and costs and analyzing drilling processes, and
3) visualization of the results.

Modern drilling tool developers can use publicly available computer technologies in engineering design to develop their own products. For example, "Ideas" by Smith Bits has successfully applied computer simulation in its design. Currently, the most popular software in the field of drilling studies today are computer-aided engineering (CAE) systems such as Nastran, Patran, and Ansys, based on the finite element method (FEM). These software enable a detailed study of even the smallest elements and parts of the design scheme [3–8]. The primary technical consideration and most important economic factor in drilling is the mechanical drilling speed, which largely depends on the rock destruction mechanism [9, 10]; thus, computer simulation the movement of an instrument that destroys a rock must include:

1) a study of the effect of changes in the layer thickness of the rock using various cutting tools;
2) the heating effect of the incisors on the contact plane with the rock to examine the conjugate flow and heat transfer of the drilling fluid;
3) the fluid pressure at various points in the well;
4) other parameters [11].

Currently, there is no methodology that would enable a complete simulation of the entire drilling cycle to determine the rate of penetration as a function of the drilling parameters and conditions because of the complexity of the processes. Most of the modeling approaches are about particular elements of the drilling cycle. A lot of recent research has been devoted toward using a FEM to simulate the interaction of a drilling tool with a rock. The primary motivation of this study is to determine the capabilities of different software packages in the computer simulation of drilling processes and the potential to reduce the time spent on preparing and computer simulation drilling processes. We conducted a case study, which models a diamond single-layer crown drilling tool, with a radial layout of large synthetic diamonds. This is considered to be the most effective tool for drilling [12, 13].

2. Model Description

In a simplified form, the position for each diamond during the operation of a single-layer crown, with a radial layout of diamonds, is determined by the rotation angle (φ) and the crown deepening (z). Furthermore, each cutting line is characterized by the bottom face coordinates ($y(\varphi)$) at each of its points. Then, the rock layer thickness, being cut by a diamond at a particular point on the face of the crown, can be determined as follows:

$$h_i = z - y_i. \qquad (1)$$

where y_i is the coordinate of the surface in front of a specific diamond. From the invariability condition, at constant weight on bit (WOB), we have the following relation:

$$\sum_{i=1}^{n_a} h_i = n_\kappa h_a. \qquad (2)$$

where h_a can be calculated by refined formulas after considering the fracture coefficients of the rock (k_p) and the diamond shape (k_a) [14]. Note that, when the crown rotates, its indentation depth increases by Δ; moreover, the following relation will be satisfied at the time of each act of rock destruction:

$$\sum_{i=1}^{n_a} (z - y_i + \Delta) = n_\kappa h_a. \qquad (3)$$

where Δ is the indentation depth of the crown on each indentation act on the rock. From equation (3), we determine the value of Δ, which corresponds to a particular position of the crown on the bottom [15].

$$\Delta = \frac{n_\kappa h_a - \sum_{i=1}^{n_\kappa}(z - y_i)}{n_\kappa} = h_a - \frac{1}{n_\kappa}\sum_{i=1}^{n_\kappa}(z - y_i). \qquad (4)$$

3. Computer simulation in the study of processes that occur during drilling

FEM delivers good results when modeling very complex systems without the need to create specialized mathematical models. The first stage is preparing the problem's geometry. For computer simulation a drill crown, this stage is very tedious. To reduce the time spent on preparing the model's geometry, particularly in the case of changing the model parameters, it makes sense to use software tools to automate this task. Almost all modern CAD software have the capability to create parametric models. We used KOMPAS-3D to develop a parametric model, which automates the construction of the diamond crown geometry. [19] When using this model, you can specify the following design parameters of the crown:

1) the outer and inner diameter;

2) the number of sectors;

3) the number of diamonds in the sector;

4) the sector height;

5) the parameters of the layout of the diamonds;

6) other parameters.

An example of the geometry obtained from the model is shown in Fig. 1.

Using this approach, we considerably reduced the time spent on preparing the model's geometry when changing parameters. For a detailed study of the distribution of the mechanical loads on the crown, FEM was used to simulate the crown at the bottom of the well. Moreover, modeling was carried out after considering axial and twisting forces. As boundary conditions, we applied axial load and torque on the top of the model and a fixed support on the bottom face of each diamond. Fig. 2 shows the results of this modeling step for a diamond crown with four radial rows in each sector, with a WOB of 20 kN at 1000 rotations per minute (RPM). Using the crown geometry data obtained as a source, a FEM simulation with various available FEM software packages is run.
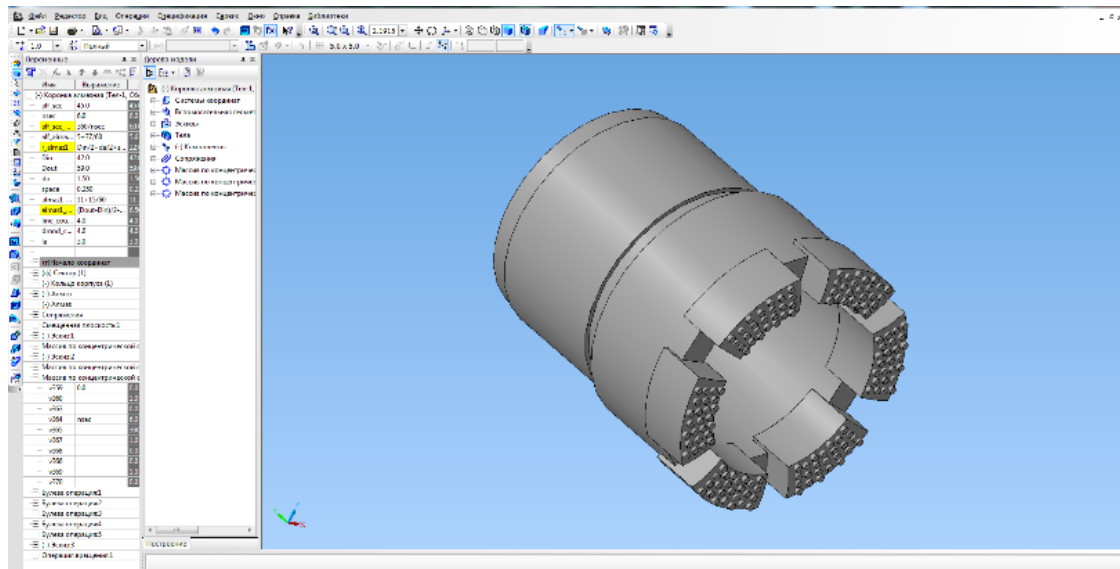

Fig. 1. An example of modeling the design of a diamond, single-layered crown, with a diameter of 59 mm
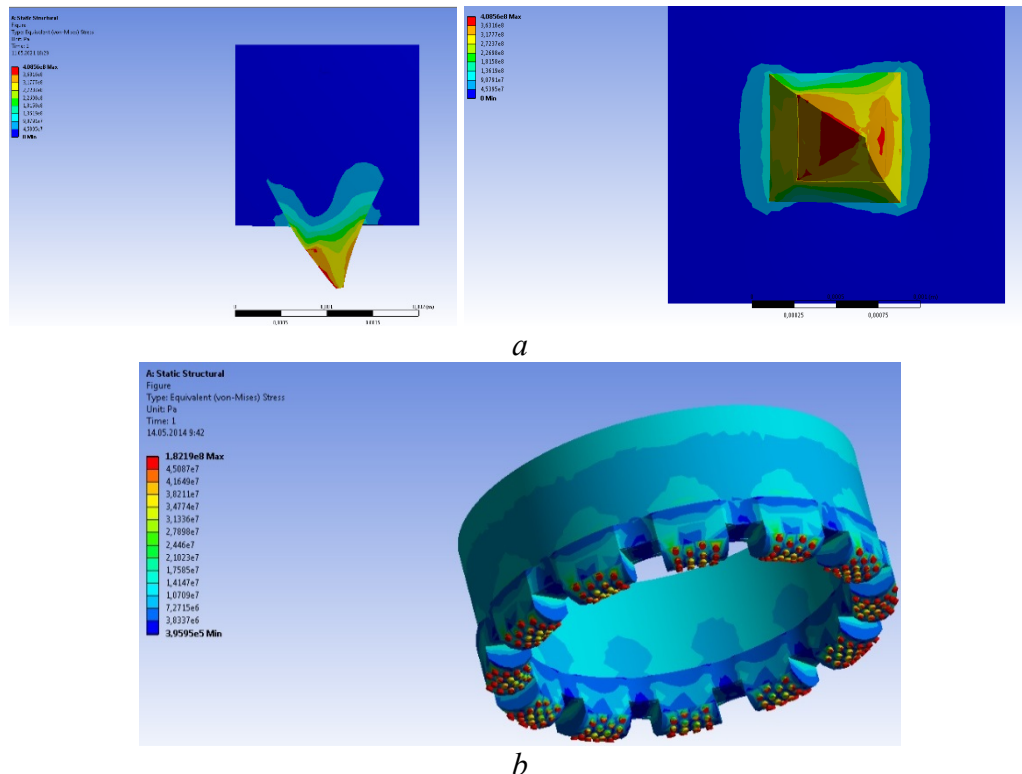

a

b

Fig. 2. Schematic of the distribution of mechanical stress: a – in one, maximally loaded diamond while working the crown; b –in the crown after considering the effective axial load and torque

We used to

1) apply physical and mechanical properties and form of the diamonds,

2) investigate the method of fixing diamonds in the matrix; and

3) analyze different drilling regimes.

The simulation results are visualized well and enable us to draw conclusions about the potential for drilling using sectors of four radial rows [16].

Although this model enables us to evaluate the mechanism of drilling a well, it is not suitable for modeling a well's drilling because of the huge computational costs involved. To solve this problem, using the simulation results obtained from FEM, the abovementioned drilling model was implemented. When selecting software to implement the model, the main requirementwas to visualize the simulation results in the minimum amount of time when changing the model parameters. Using the Delphi programming language, a drilling process model was developed by the employees of Donetsk National Technical University. The program enables

1) simulation of the movement of a single-layer diamond bit on the well bottom;

2) determination of the rock layer thickness cut by each diamond at a particular time;

3) determination of the coordinate of the bottom crown end; and

4) the display of the diamonds' movement trajectory in the axial direction as the lower end of the crown moves.

Using Delphi reduced the time spent on the Graphical User Interface (GUI) and the visualization of the modelling results for tool development. This program can be used to consider the diamond layout and the crown design parameters. This enables us to make a comparative assessment of the diamond layout effect on the crown end movement, as well as on the load magnitude of each diamond during the drilling process. The initial data for modeling are as follows:

1) the coordinates of each diamond are located on the crown;

2) the initial value of penetration of the diamonds due to an axial load;

3) the total number of modelling points into which the cutting line is divided.

There are three ways to input the initial data on the diamond layout:

1) manually;

2) using a pattern (Fig. 3a);

3) load from a file.

User can change measure units with special switch in the diamond coordinate's input field. The correctness of the data input can be verified by visually assessing the location of the diamonds (Fig. 3b).
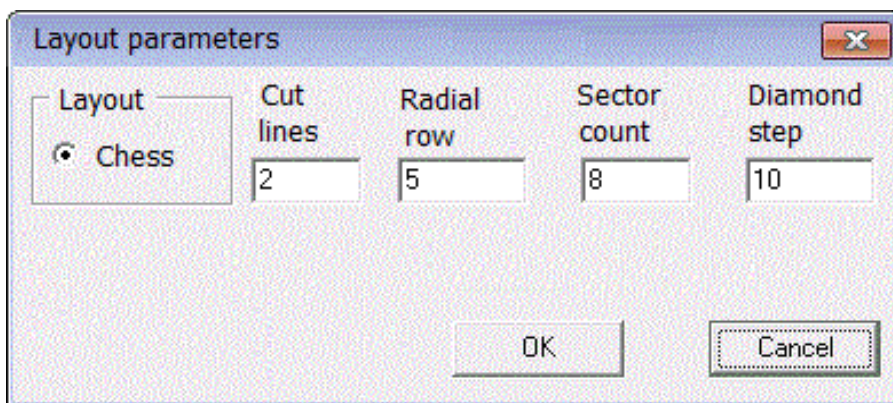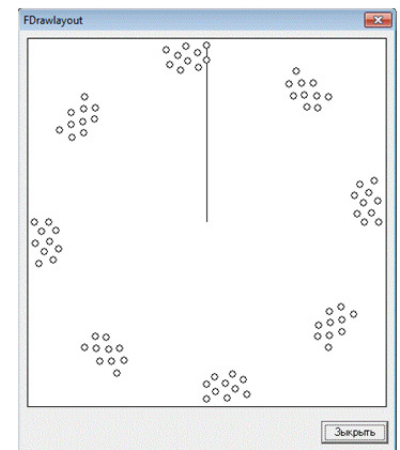
a   b

Fig. 3. Example view of the program interface: a - a window for entering the layout of diamonds from the template; b–a diamond layout control window

With the "Pause" button (Fig. 4), you can record the results at any time without interrupting the modeling process, and the "Show face" button will show the cross-sectional plan at this point. Clicking on the "Layout" button displays a second window (Fig. 4), where the thickness of the cut rock layer is graphically displayed for each diamond, along with color coding. With a mouse click, you can select any of the diamonds, and the current layer thickness will be displayed on the right. The color of the diamonds shows their loading: the most loaded are displayed by dark colors, while the less loaded by lighter colors (Fig. 4).
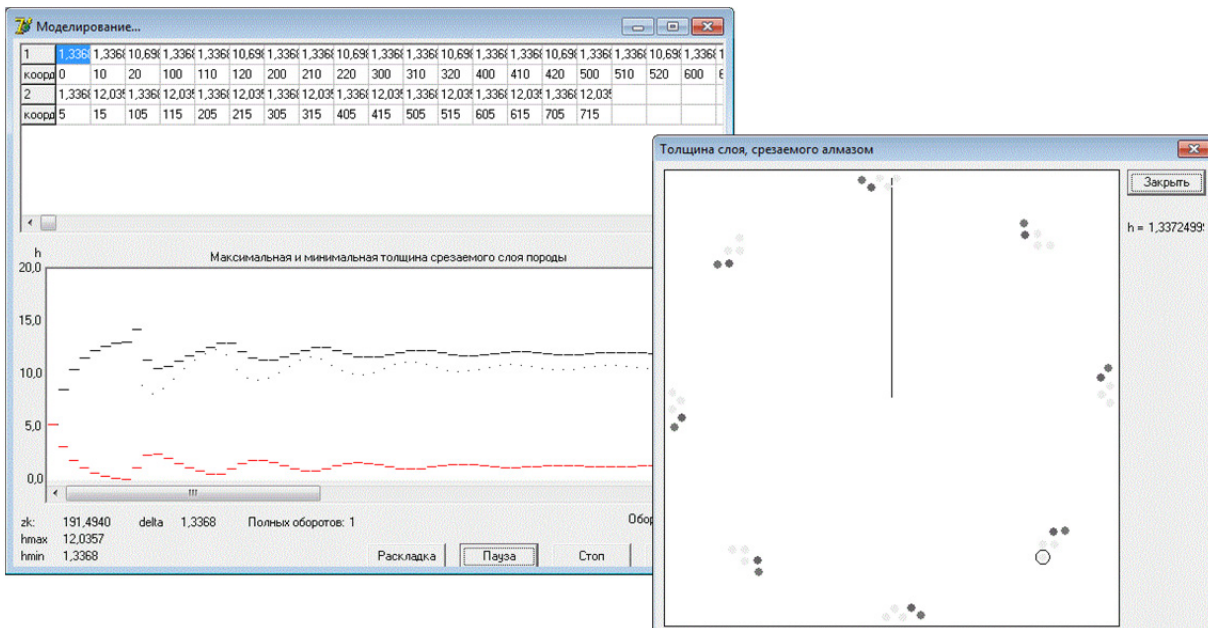
Fig. 4. Windows of simulation results

Computer simulation has shown that a single cutting-line of diamonds cuts a different thickness of the rock layer to that cut by diamonds from the first radial series. This depends on the layout of the diamonds and varies with time; however, this software suffers from several drawbacks. The program we have developed does not consider the properties of the rock, the profile of the cutter, or different drilling modes. The primary limitation was the tedious procedure needed to change the model and visualization tools as the model and modeling improved. Tuning a model required changes to the source code of the program, which depended on advanced programming skills to avoid any potential errors. Therefore, we used another software product, LabVIEW, which made it possible to significantly simplify making changes to the model and improved the quality of the results. This was done because of LabVIEW's ability to increase the complexity of the model without significantly complicating its implementation. One of the primary products of National Instruments is the LabVIEW graphical programming environment [18]. To ensure the possibility of executing parallel programming elements, LabVIEW can enable certain simplifying assumptions. LabVIEW is used for data collection and processing systems, as well as for managing technical objects and technological processes. LabVIEW is used to solve various research problems. In future, LabVIEW's functions will extend the potential uses of the model we have developed, particularly when the model can be used in combination with LabVIEW's capability of experimental data acquisition in real time. Because of the parallel programming principle, it is possible to simulate the behavior of all the incisors and the effects of the cutters on each other. The graphical programming environment of LabVIEW enables the creation of a friendly GUI, characterized by a flexible and easy configuration. Fig. 5 shows the appearance of the program, which includes

1) setting the initial values of the program, i.e., the number of lines, sectors, and radial rows of cutting;

2) a window for simulation the location of the crown bits;

3) a graph displaying the modeled maximum and minimum rock thickness cut; and

4) a graph giving a visualization of the modeling results for two levels of rock cut by two different incisors.

The LabVIEW programming environment has a large set of add-ons and libraries. One of the add-ons provides a real-time mode, which facilitates the display of changes in various geometric shapes, depending on the mathematical formulas programmed [20]. This supplement enabled the display of the dynamics of the rock cut by the diamond cutters. Fig. 6 shows the results of simulation the passage of diamond incisors through rock in two cycles of the program.

The LabVIEW implementation is more up-to-date, because this programming language contains new researching tools for scientific research. However we need to adding more functions for full drilling process simulation.
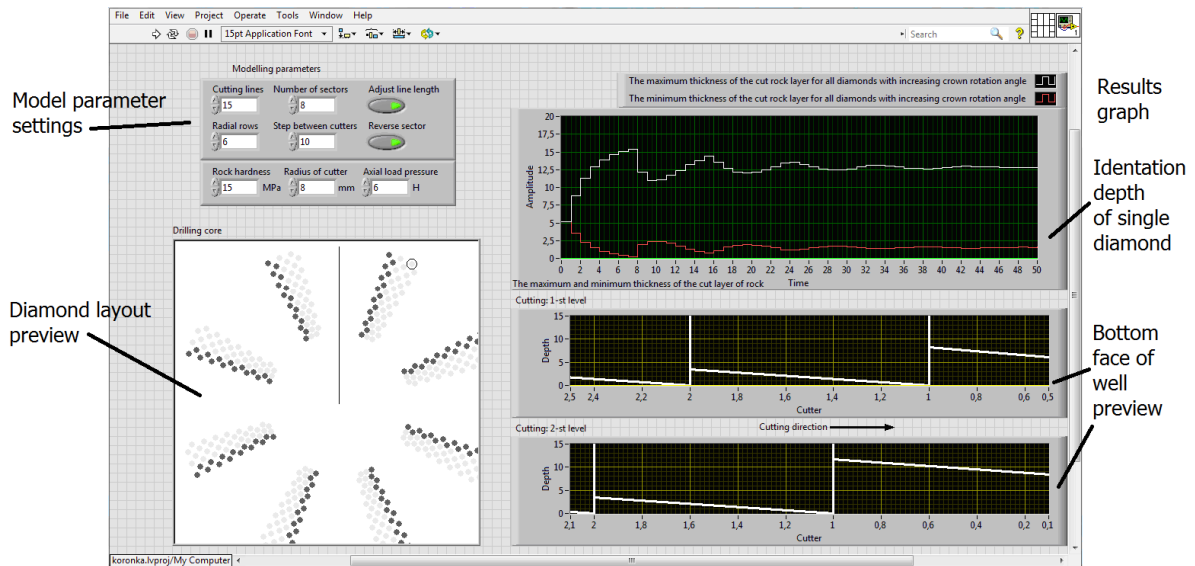
Fig. 5. The diamond crown motion simulation program interface (LabVIEW programming environment)
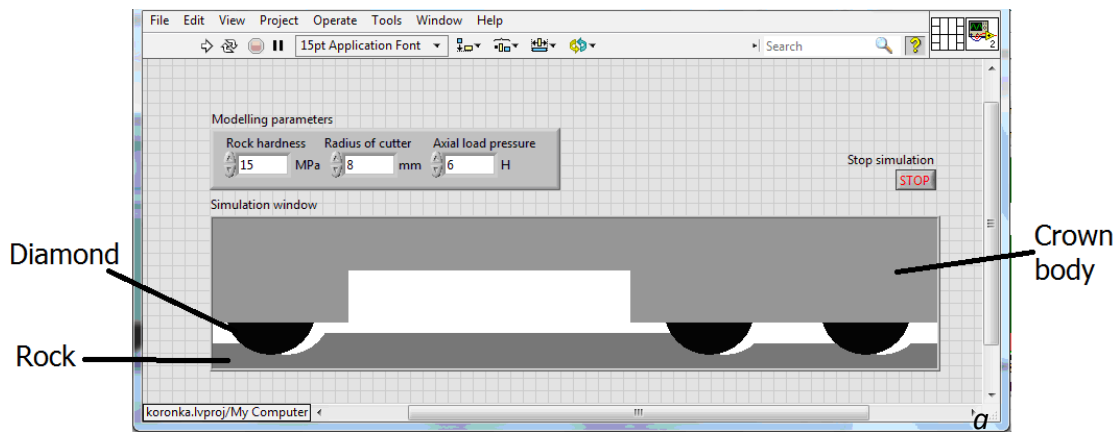

Fig. 6. Computer simulation the passage of diamond cutters through the rock: a – the static introduction of the crown into the rock; b – rotation of the crown by an angle equal to the distance between two adjacent diamonds in the cutting line

4. Summary

In this case study, we modeled the drilling process by sub-modeling the interaction of a rock-cutting tool with a rock with the aim of designing an optimal drilling crown. The results of this study demonstrate the following:

• a complex modeling system is required for well drilling and that the scientific research should be based on an integrated approach [4];

• drilling simulation problems can be solved using modern programming tools;

• computer simulation makes it possible to consider all factors that influence drilling;

• computer simulation enables us to perform research on small elements and places of the calculation scheme;

• computer simulation helps in both the analysis process and the visualization of the results.

Thus, for modeling the drilling process, we propose the following workflow:

• using a modern CAD software with the capability for parametric modeling of the geometry to reduce the time spent on changes and preparing a geometric model for FEM analysis:

• using FEM to determine the parameters of the interaction of the crown with the rock;

• using modern software, such as LabVIEW or similar software, for implementing mathematical models with wide visualization capabilities and simple GUI creation tools;

• using software tools, such as LabVIEW, which enable the integration of the modeling process and the experimental data collection when conducting physical modeling experiments.

Based on this workflow, the time spent on obtaining the modeling results for such a complex process as the diamond crown drilling of wells will be significantly reduced.

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