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USE OF MULTIBODY SYSTEM APPROACH FOR TORQUE AND DRAG ANALYSIS OF LONG DRILL STRINGS

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Computer simulation is widespread approach to torque and drag analysis of drill strings. It is important phase of designing wells and selecting fit parameters of drilling operations. Dynamic simulation of the long drill strings are related to some problems. One of the problems is a large number of degrees of freedom of the models. The second one is stiff equations of motion that require special integration methods. For calculating very long drill strings, so called soft-string models ignoring bending stiffness are commonly used. Such models give quite accurate results for axial loads and torque if the drill string does not buckle. But it cannot compute contact forces between the drill string and wellbore, cannot simulate buckling and real drill string rotation.

In this paper, a multibody system approach to simulation of dynamics of the long drill strings is suggested**.** The aproach is described in detail in paper [1]. A drill string is simulated as a set of uniform flexible beams connected via viscous-elastic force elements. Each beam can undergo arbitrary large displacements as absolutely rigid body but its flexible displacements due to elastic deformations are assumed small. A method of floating frame of reference for flexible bodies and component mode synthesis is used for modeling beam dynamics. Parameters of the coupling force elements are calculated automatically based on stiffness and inertia characteristics of the connected beams. The approach allows simulating dynamics of drill strings including such processes as vibrations, rock cutting, friction, hydraulics as well as buckling and post-buckling behaviour. Its use for the torque and drag analysis is considered below.

In order to overcome limitations related to the large number of degrees of freedom and to increase effectiveness of the simulation, the algorithm for parallel generation and numerical solution of equations of motion are developed. Parallel multi-thread computations for multi-core processors are implemented according to the fork-join method. The analytic expressions for Jacobian matrices of stiff forces are derived and applied within implicit Park method to increase the integration step [3].

Torque and Drag Analysis of a drill string is reduced to the search of equilibrium conditions under given loads. A small value of the kinetic energy of the drill string is the criterion to finish the integration of the equations of motion. To increase the convergence of the calculations, unrealistic (additional, not present in reality) internal and external damping forces are applied to the drill string. It can lead to the problems of simulation of very long drill strings when the processes with very low frequencies are observed. For example, torsional vibrations of the drill string of six kilometers in length are not completely damped when the threshold value of the kinetic energy equal to 1 Joule is reached. Therefore, equilibrium values of axial torque are wrong. Further decrease the boundary value of the kinetic energy leads to multiple increase the simulation time. The calculations can take few hours.

To improve the approach, a three-step algorithm for solution of the problem has been developed. In the first step, initial values of the displacements and rotation angles of drill string parts are calculated using static equations. The drill string is considered as a chain of absolutely rigid segments connected via joints in their ends. The forces and moments in the interconnections of the segments are obtained from equilibrium conditions of each segment sequentially segment-by-segment. The boundary conditions for the first segment are defined by parameters of the torque and drag operation. Flexible displacements and rotation angles of drill pipes expressed in the modal coordinates are computed using the results of the static solution.

On the second step, the calculated longitudinal displacements and forces are applied to the full dynamic model of the drill string and equilibrium conditions are computed by integration of equations of motion. Finally, rotation angles and axial torques are set and then values of all parameters corresponding to the operation conditions are obtained by integration.

Applying the described algorithm, it takes less than fifteen minutes for simulation of the rotary drilling operation with the drill string 10 056 meters in length using four threads of the 3 GHz multicore processor. The model of the drill string includes 2189 flexible beams and has 26 304 degrees of freedom.

The results of the developed method have been compared with classical soft string and other stiff string models and compare very well.

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