Drilling Simulations Enhance **Well Planning and Drilling Decisions**

MSC Software Partners with Pioneer Natural Resources to create Adams Drill Platform

By **Fred Harvey, MSC Software**

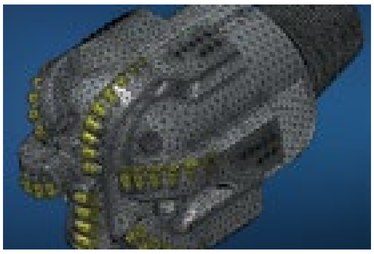
Exploration for oil and gas involves drilling a well with a length of drill pipe attached to a Bottom Hole Assembly (BHA) that includes a variety of specialized drilling tools for boring through rock, taking measurements, managing vibrations, and steering control. The drill string follows a trajectory intended to reach a particular oil rich target zone, often exceeding 15,000 feet from the drill rig itself. Since each well is unique, and the drilling process is incredibly expensive, it is impractical to physically test the design as with traditional prototype testing.

The drilling system is complex and includes fluid systems, electrical systems, advanced control systems, mechanical drives, rig structure, and drill string in addition to Mother Nature, who contributes to the environment with high temperatures and pressures and a wide range of geology considerations. The drill string is immersed in drilling fluid and remains in contact with the wellbore through many layers of formations, each with different physical properties. Rotation and axial motion is controlled at the surface by electric top drive and cable systems; each with their own mechanical, hydraulic, and control systems. Drilling fluid is pumped through the drill pipe and up the wellbore to provide lubrication, cooling, and evacuation of rock cuttings from the bit. This fluid provides viscous damping and buoyancy effects to the drill string, but also has a tendency to cake when left static. Mud motors convert hydraulic energy into mechanical energy that provides torque and additional RPM to the drill bit. Other devices with varying degrees of sophistication are used to take measurements, manage vibrations, and stabilize and maintain directional control of the BHA. All of these devices must be accounted for in the model in order to capture the correct system behavior. As one can imagine, the drilling system as a whole is very complex, comprised of numerous nonlinear subsystems that interact with fluids, geology, control systems, and mechanical structure of the string itself. With such a complicated system, it is no surprise that damaging vibrations can occur downhole with little or no indication at the surface. Physical testing is not only prohibitively expensive, but the test data are often not available until after the drilling is completed and downhole data is made available. Even with downhole test data, it is very difficult to comprehend what is actually happening from the

limited information available. Modeling provides an opportunity to study the drilling system, make sense of available physical data, and estimate behavior of future designs.

Many approaches have been used to model drilling with various degrees of success. Finite elements are most common. On one end of the spectrum, very simple linear structural dynamics models have proven to be a very useful representation of the string for basic planning purposes. Advanced nonlinear FEA models used by the major service companies have been used to study the nonlinear drilling dysfunctions. Although FEA is appropriate for capturing nonlinear behaviors, such models tend to be cumbersome, computationally expensive, and are not commercially available. Systems of equations are on the other end of the spectrum. Fast enough to be used in real time analytics, but difficult to capture enough fidelity to account for individual designs or the complex coupled physics.

A Multi Body Dynamics (MBD) approach with MSC Adams strikes a nice balance between fidelity and computational efficiency while capturing the coupled three dimensional nonlinear behaviors of the drilling system and various subsystems. MSC Software has partnered with Pioneer Natural Resources to tailor fit Adams to this unique industry vertical application. “We’re very excited about the potential for Adams Drill,” said Chris Cheatwood, Chief Technology Officer at Pioneer. “This software allows us to simulate drilling an entire well from start to finish, monitoring a range of



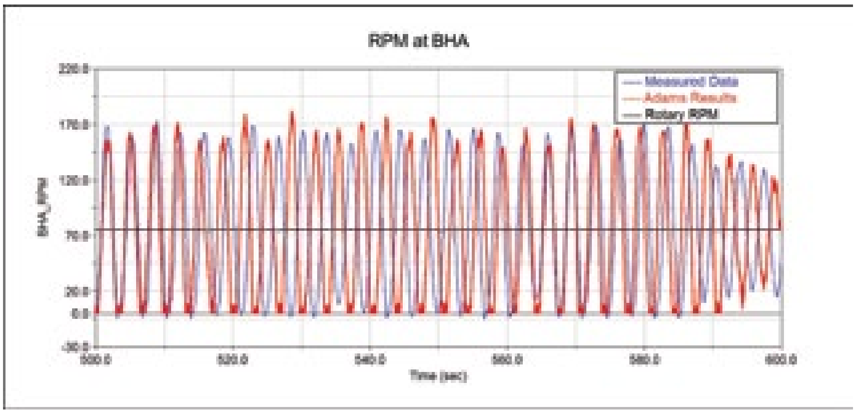


Figure 1: Comparison of measured and simulated RPM at the Bottom Hole Assembly.

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Chris Cheatwood, Chief Technology Officer, Pioneer

new parameters we’ve never had access to before.” Pioneer is helping MSC validate the models by collecting physical drilling data with special measurement subs that are designed to withstand the extreme vibrations and downhole operating environment during drilling. The team is using the measured data for comparison with simulation data to verify accuracy of the models and improve them as necessary. Figure 1 shows a high level of correlation between the measured and simulated RPM recorded just above the motor in the Bottom Hole Assembly.

These recording subs are capable of measuring torque, rpm, axial load, and bending moments at various locations in the BHA at 50 Hz for long periods of time. Such downhole data is critical to calibrate and gain trust in a comprehensive drilling model such as this. Similarly, the model is critical to rationalize the nonlinearities observed in the physical data and understand how changes to the BHA design, wellbore trajectory, lithology, operating parameters, and control systems, will impact drilling system dynamics.

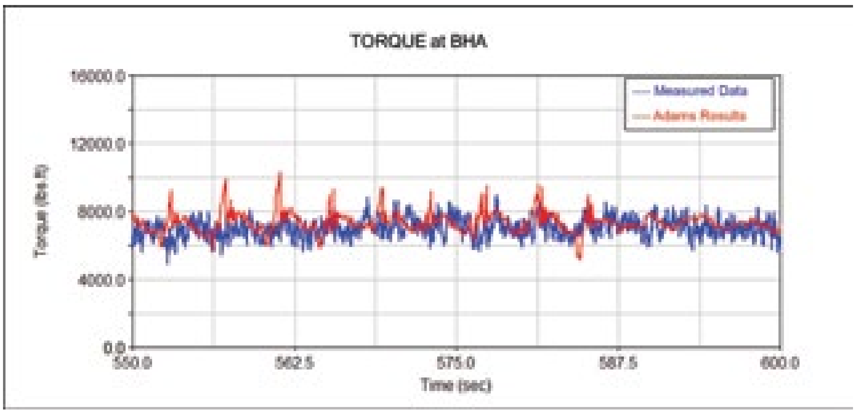

Figure 2: Comparison of measured and simulated torue at the Bottom Hole Assembly.

Figure 2 compares simulated and measured torque fluctuation in the bottom hole assembly. The efficiency of the Adams solver enables users to systematically exercise the model over a wide range of environmental parameters in order to refine estimates of the unknowns and learn why the system behaves the way it does. Variables like friction, damping, bit/rock interaction, and top drive control system response are not often well understood or predicted before drilling so the model is used to estimate the unknowns and verify system response with test data.

The tuned model now serves as a virtual drill rig that can be used to test various opportunities for improvement. Virtual sensors generate dynamic data along the entire drill string, which provides much more valuable insights about system behavior than is possible or practical through physical data collection alone. A systematic redesign of the BHA can be accomplished to reduce severity of vibration in order to manage risk while maximizing drilling efficiency or penetration rates. Validations of a model calibrated with physical measurements in one well and verified against measurements in the same formation in a different nearby well are promising. Specialty downhole tools can be evaluated for their potential to reduce dynamic dysfunctions. Drilling Engineers can optimize the placement of specialty tools in the BHA and establish best practices and choose optimum operating parameters to mitigate risk of dysfunction. Specialty tool vendors can even explore how the design parameters of their particular tool influence their customers' drill string behavior. Control systems can be tested virtually for their ability to improve performance over a wide range of operating conditions. And operators can study the conditions leading to component failures in order to learn from and avoid similar circumstances in the future. All of this can be done virtually, enabling drilling engineers to explore the system response and make educated decisions throughout the design process.

Risk can be defined in a multitude of ways from exceeding load limits to high stress concentrations, excessive vibrations, known dangerous conditions, or well defined dynamic dysfunctions like stick slip or whirl. Elevated risks can be avoided or managed through thoughtful consideration of alternatives or accepted under extreme circumstances. A three dimensional plot is generated by exercising the simulation across a wide range of operating conditions and at multiple depths in the wellbore. Risk severity is assessed by compiling a number of factors related to loads, motions, and dynamics known to cause damage or non-productive time. Engineers can see how the level of risk is expected to change under various conditions as drilling progresses. Alternative designs can be compared to seek further improvement on subsequent wells. And the risk associated with any particular factor can be weighed more or less heavily depending on the particular limiters that are most costly or experienced most often. "This lets us test multiple designs in parallel and compare the results side-by-side to quickly hone in on the optimal configuration for each well," Says Cheatwood.

Adams Drill captures the real-world nonlinear system behaviors and enables engineers to make sound design and operational decisions that improve the drilling process, reduce risk of failures, increase drilling efficiency, and increase production opportunity.

About Pioneer Natural Resources

Pioneer is a large independent oil and gas exploration and production company, headquartered in Dallas, Texas, with operations in the United States. For more information, visit Pioneer's website at www.pxd.com.

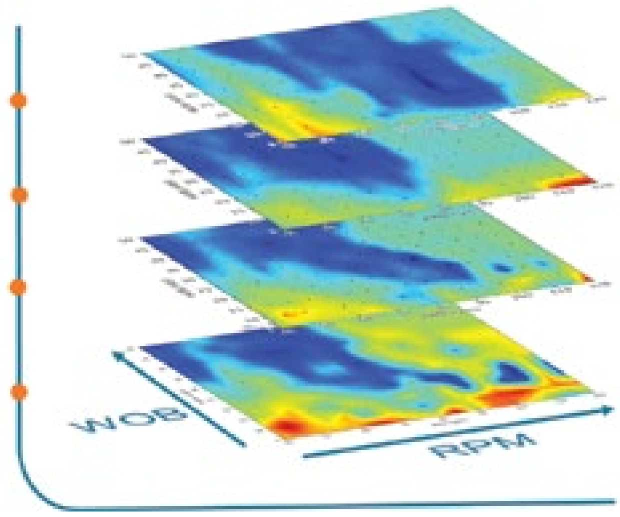

Figure 3: Risk assessment at various weight on bit, rotation speeds, and measured depth.