Modeling and Control of Well Hydraulics and Drilling Vibrations

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Modeling of Well Hydraulics System

Background

- Gas kicks occurs when wellbore pressure < reservoir pressure
- Conventional indicators: increasing pit gain, flow out rate, deviations in pump pressure, etc.
- Conventional well control methods:
  - Stop pump and flow check
  - BOP shut-in
  - Circulate kick out with Driller's or Wait & Weight method
- Managed pressure drilling (MPD):
  - Increase back-pressure with MPD choke
  - Constant bottom hole pressure kick circulation

Mathematical Model

- Partial differential equations
  - Two phases: liquid (drilling fluid) and gas (formation or injection)
  - Multiple **mass conservation equations** for each liquid and gas components
  - One **momentum conservation equation** for the mixture (drift-flux model)

$$\partial_t A(x)\begin{bmatrix}\alpha_{l,i}\rho_{l,i}\\ \vdots\\ \alpha_{g,k}\rho_{g,k}\\ \vdots \\ \left(\sum_{i=1}^{I}\alpha_{l,i}\rho_{l,i}\right)v_l+\left(\sum_{k=1}^{K}\alpha_{g,k}\rho_{g,k}\right)v_g\end{bmatrix}+\partial_x A(x)\begin{bmatrix}\alpha_{l,i}\rho_{l,i}v_l\\ \vdots\\ \alpha_{g,k}\rho_{g,k}v_g\\ \vdots\\ \left(\sum_{i=1}^{I}\alpha_{l,i}\rho_{l,i}\right)v_l^2+\left(\sum_{k=1}^{K}\alpha_{g,k}\rho_{g,k}\right)v_g^2+p\end{bmatrix}=A(x)\begin{bmatrix}q_{l,i}\\ \vdots\\ q_{g,k}\\ \vdots\\ f_w+f_G\end{bmatrix}$$

- Closure algebraic equations

Slip law:
$$\begin{cases} v_g = C_0 v_{mix} + v_d \\ v_{mix} = \left(\sum_{i=1}^{I}\alpha_{l,i}\right)v_l + \left(\sum_{k=1}^{K}\alpha_{g,k}\right)v_g \end{cases}$$

- Downward/upward flow
- Flow regime dependent

Density:
$$\begin{cases} \rho_{l,i} = \rho_{l,i}(p,T) \\ \rho_{g,k} = \rho_{g,k}(p,T) \end{cases}$$

- Linear fluid density model
- Hall-Yarborough real gas density model

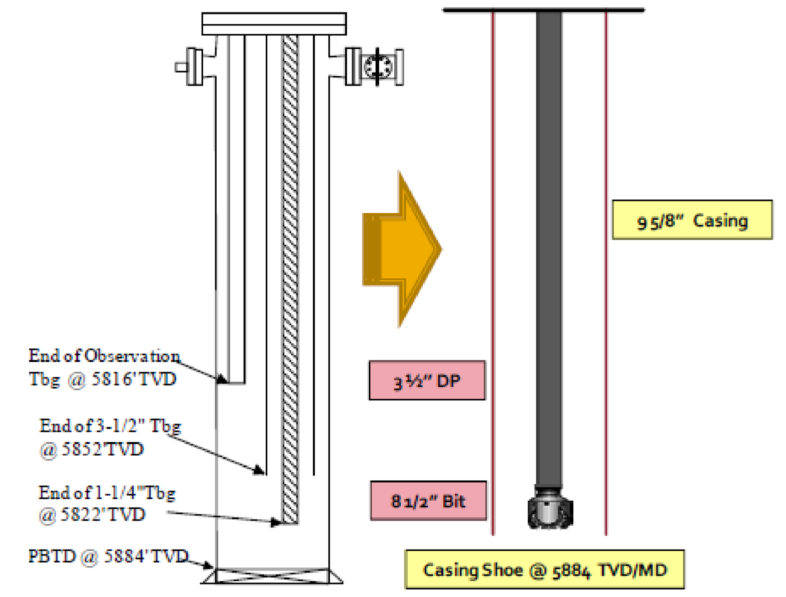
Void fractions:
$$\sum_{i=1}^{I}\alpha_{l,i} + \sum_{k=1}^{K}\alpha_{g,k} = 1$$

- Source term modeling
  - Non-Newtonian frictional force
    - Yield power law fluid
    - Lee-Gonzalez-Eakin gas viscosity model
  - Two phase choke/bit nozzle model
  - Reservoir model (Production index model)
  - Fracture model (Two-stage model)

Model Validation

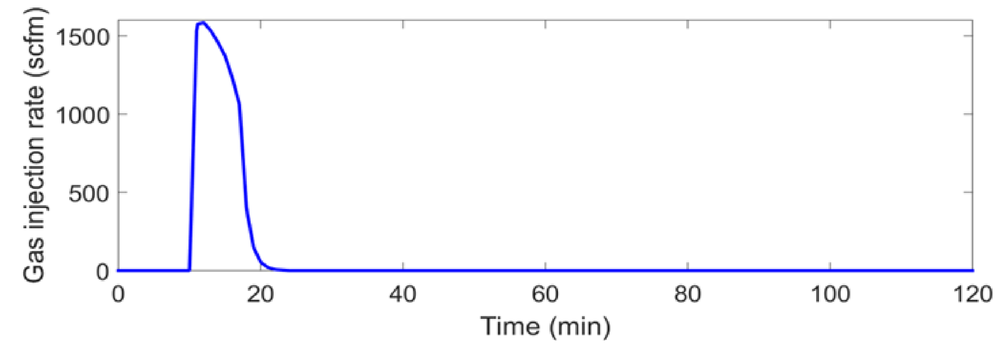
Experimental Setup

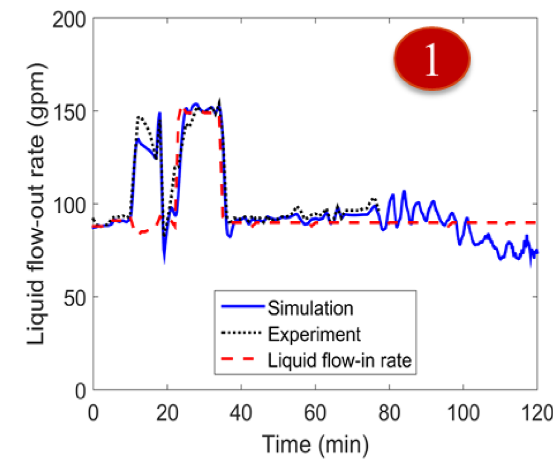
Property	Value
Well depth	5,884 ft
Casing shoe depth	5,884 ft
Casing size	9.625 in
Drill pipe outer diameter	3.5 in
Gas injection tubing diameter	1.25 in
Circulation rate	90-150 gal/min
Mud weight	8.6 lb/gal
Plastic viscosity	8 cP
Yield point	2 lb/(100ft^2)
Bulk modulus	2.15×10^5 psi
Choke valve coefficient	0.107 ft^2
Choke gas expansion factor	0.25
Surface temperature	93 °F
Bottom-hole temperature	140 °F



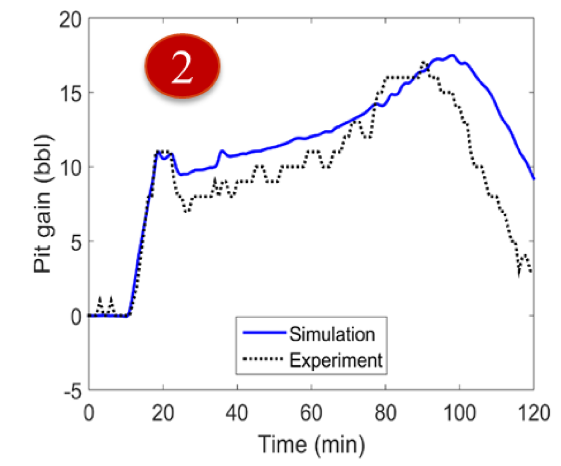
Gas injection rate vs. time

Parameters
1) Flow in/out
2) Pit gain
3) Surface backpressure

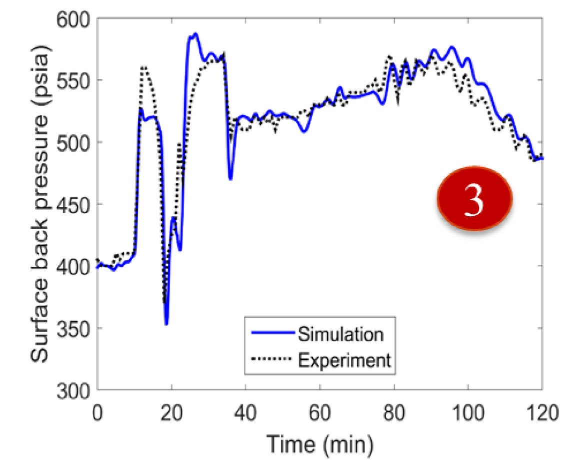




Flow in/out



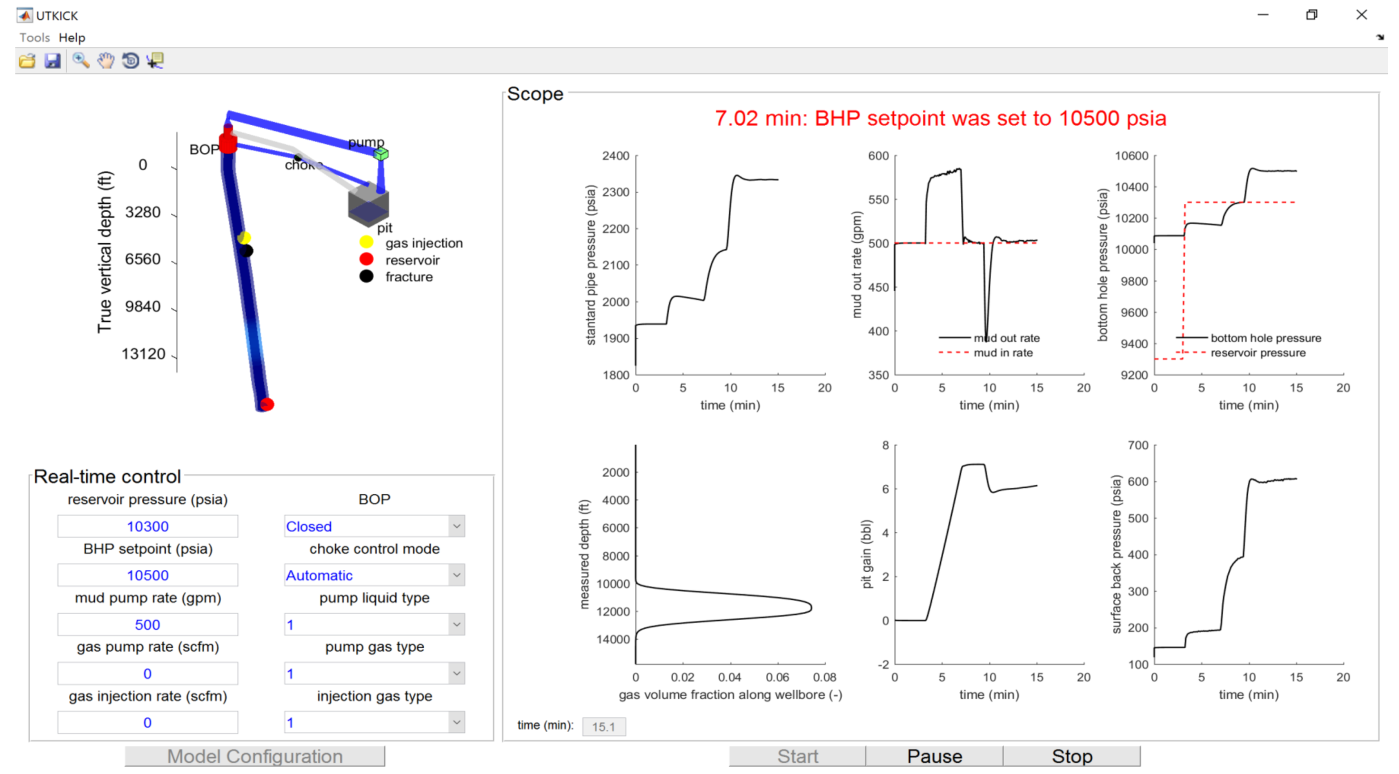
Pit gain



Surface pressure

UTKICK – A Well Control Simulator

- Virtual downhole sensor/observer
- Interactive user control for training rig personnel
- Well design application (determine suitable mud type, weight etc.)
- Create different kick scenarios for training data-driven kick detectors

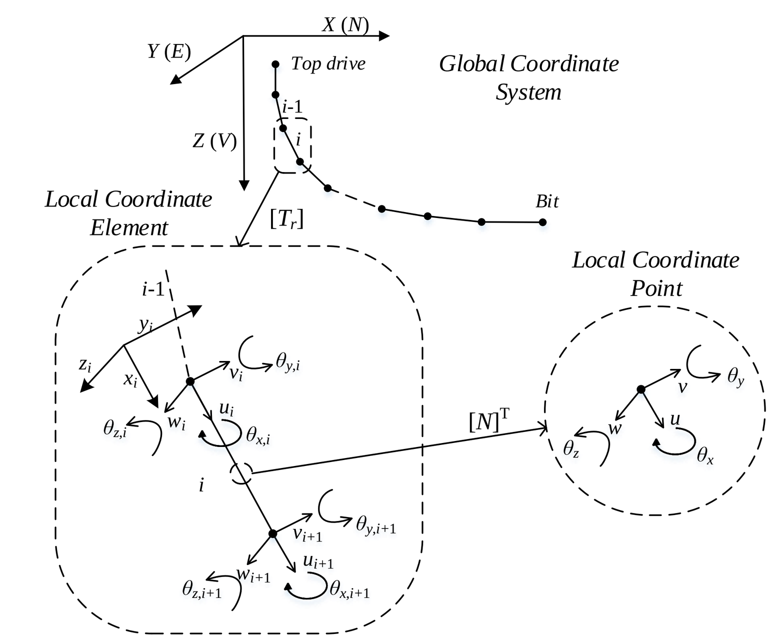


Modeling and Control of Drillstring Vibration

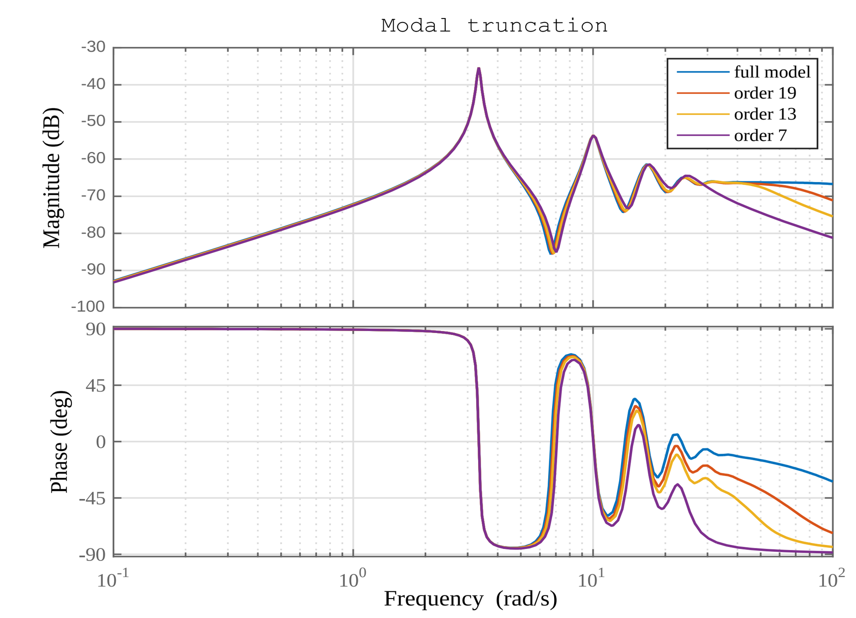
Accomplishments

- A six DOF FEM model was developed to simulate drillstring and BHA dynamics;
- A comprehensive B.C. was developed to describe bit-rock interaction, including
  - BHA eccentricity
  - Mud hydrodynamics
  - Bit-rock collisions in axial and lateral directions;
- A control-oriented model was developed through order reduction;
- Drillstring vibration mitigation methods were developed.

Dynamic FEM Model

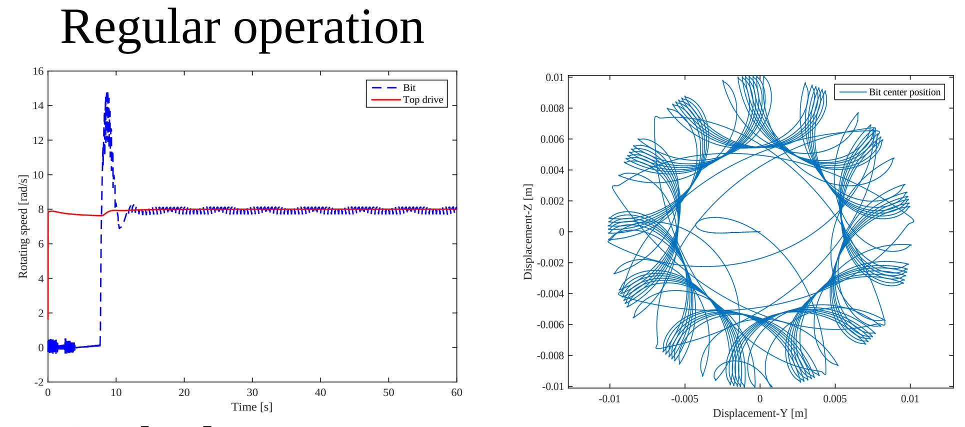


Reduced-order Model

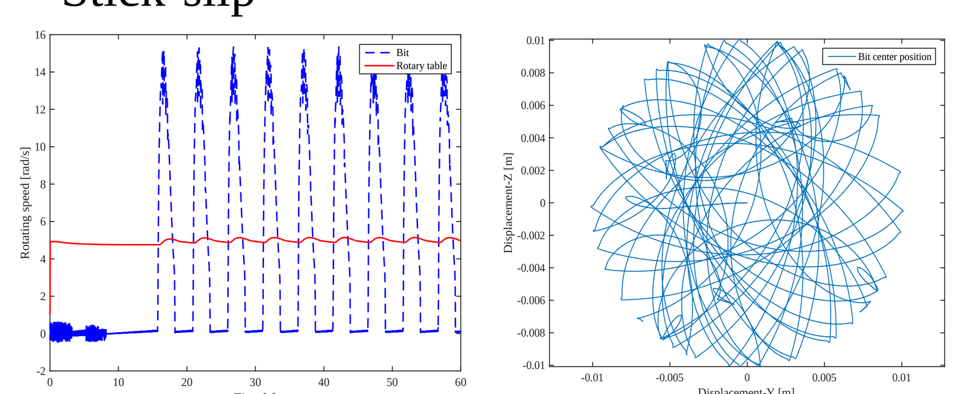


Drillstring Vibration

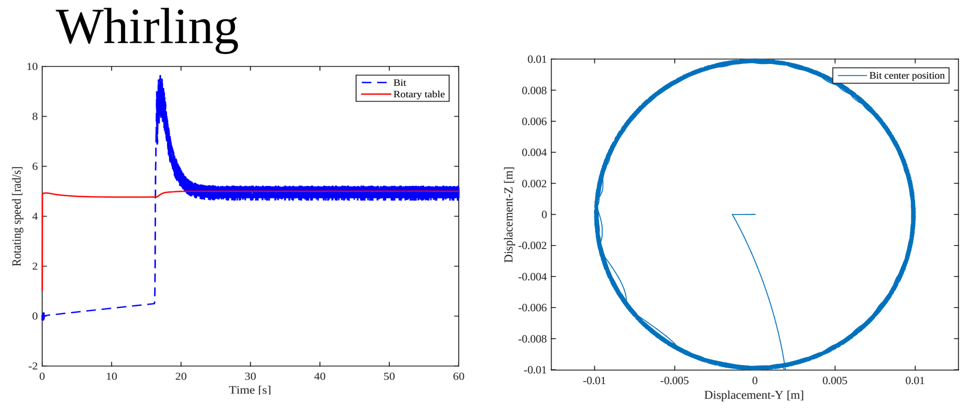
Regular operation



Stick-slip

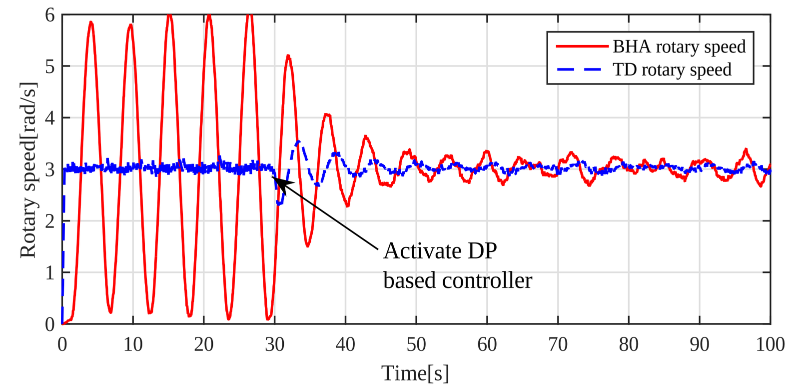


Whirling



Vibration Suppression

Active control



BHA structure redesign