SPE-184610-MS

Improved Bottomhole Pressure Control with Wired Drillpipe and Physics-Based Models

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Outline

- Opportunities and Challenges with MPD Automation
- Non-linearity in the MPD operation
- Nonlinear Model based Control Strategy (H-W Model)
- MPC Model Configuration (Controller Matrix)
- Normal Drilling and Pipe Connection (Performance comparison w/ PID)
- Multi-Variable Control Strategy for Kick Attenuation
- Conclusion
Advances in Downhole Data Access and Physics-based Models


See https://github.com/APMonitor/drilling
Nonlinearity in Managed Pressure Drilling

Increasing Mud Flowrate

Operation Range

BHP (bar)

Mud Flowrate (m³/min)

Downhole Pressure vs Choke Valve Opening

Downhole Pressure vs Mud Pump flowrate

Increasing Choke Opening
Why is the Nonlinear Model needed in Drilling?

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**BHP (bar)**

**Linear Model**

**HW Nonlinear Model**

**Agreement with nonlinear model**

**Model mismatch with linear model**

45% VS 80%
Hammerstein – Winner Nonlinear Approach

Model Structure

\[ u(t) \xrightarrow{\text{input nonlinearity } F} w(t) \xrightarrow{\text{linear dynamic model } G} z(t) \xrightarrow{\text{output nonlinearity } H} y(t) \]

HW Model In the MPC Controller

\[ \text{Process} \quad y(t) \xrightarrow{\text{MPC}} w(t) \xrightarrow{\text{F}^{-1}} u(t) \]

\[ \text{Linear Space} \quad \text{Nonlinear Space} \]

- \( S_{\text{Pi}}, S_{\text{Ilo}} \)
- \( \text{SP}_{\text{Pi}}, \text{SP}_{\text{Ilo}}^* \)
Advantages of Model Predictive Control

Conventional (PID)

Advanced (MPC)

“sees” into the future to make optimal MV moves
### Advantages of Model Predictive Control

<table>
<thead>
<tr>
<th>CV</th>
<th>MV / DV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Choke Opening (Z\text{choke})</td>
</tr>
<tr>
<td>BHP (P_{bit})</td>
<td>-</td>
</tr>
<tr>
<td>Flow Balance (q_{bal})</td>
<td>-</td>
</tr>
</tbody>
</table>

- Manages multiple CVs and MVs simultaneously (MIMO Control)
- Disturbance compensation
Case Study

Three common scenarios in drilling operation

1. Normal Drilling Operation
2. Pipe Connection Procedure
3. Kick Attenuation
### Vertical Well Configuration (WeMod)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (AES)</th>
<th>Value (SI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well depth</td>
<td>11,800 ft</td>
<td>3,600 m</td>
</tr>
<tr>
<td>Riser inner diameter</td>
<td>19”</td>
<td>0.48 m</td>
</tr>
<tr>
<td>Water depth</td>
<td>590 ft</td>
<td>180 m</td>
</tr>
<tr>
<td>Casing inner diameter</td>
<td>9”</td>
<td>0.23 m</td>
</tr>
<tr>
<td>Casing depth</td>
<td>7,100 ft</td>
<td>2,164 m</td>
</tr>
<tr>
<td>Drill string average outer diameter</td>
<td>4.5”</td>
<td>0.12 m</td>
</tr>
<tr>
<td>BHA length</td>
<td>150 ft</td>
<td>45.7 m</td>
</tr>
<tr>
<td>BHA average outer diameter</td>
<td>6.7”</td>
<td>0.17 m</td>
</tr>
<tr>
<td>Open hole/bit size</td>
<td>8.5”</td>
<td>0.2 m</td>
</tr>
<tr>
<td>Reservoir depth</td>
<td>9840 ft</td>
<td>3,000 m</td>
</tr>
<tr>
<td>Reservoir Pore Pressure</td>
<td>401.0 bar/1.364 s.g.</td>
<td>401.0e+05 Pa/1.364 s.g.</td>
</tr>
<tr>
<td>Initial mud density</td>
<td>1.24 s.g.</td>
<td>1.24 s.g.</td>
</tr>
</tbody>
</table>
Normal Drilling

PID (conventional controller)

NMPC (new controller)

Better Setpoint tracking performance

Adjust 2 MVs simultaneously

Adjust 1 MV at a time

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Pipe Connection

Keep the BHP within ±1 bar variation w/o Oscillation

Compensate the Ramping movement of the Main Mud Pump

LMPC causes the Oscillation

Not adjusting Back Pressure Pump
Control Strategy for Kick Attenuation

- During Gas influx, Closed Loop Control Actions for normal operation will accelerate the Gas influx

**Gas Influx**
- BHP Increased
  - Choke Valve Open
  - Mud Flow / Back Pressure Pump Decrease
    - (Wrong Control Action)
  - BHP Decreased
    - More Gas introduce to the wellbore
      - (Undesired Result)

**Gas Influx**
- Turn off the BHP CV
  - Control the Flow Balance CV only
  - Choke Valve Close
    - Mud Flow / Back Pressure Pump Increase
      - (Correct Control Action)
  - BHP Increased
    - (Against the Higher Reservoir Pressure)
  - Block the Gas Influx
    - (Desired Result)
Control Strategy for Kick Attenuation

Turn off the BHP CV

Gas Influx

Turn on the BHP CV with new Setpoint

CV1

BHP

ON

OFF

ON

CV2

Flow Balance

ON

ON

ON

Control Flow Balance only

Prioritizing Limit

Set Range

time
Kick Attenuation Control

Settle down at new BHP balance

Bottomhole Pressure

CV1

Flow Balance

Mud Pump Flow Rate

Choke Valve Opening

MV1

MV2

MV3

WeMod Calculation

Takes less than 1min

Accumulated Mass of Gas Influx (WeMod)

q_{acc} [Kg]

q_{bal} [bar]

q_p [m^3/min]

Time (sec)

Time (sec)
Conclusion

• HW NMPC has better set point tracking in normal operation because it simultaneously moves two MVs at the same time (choke valve opening and mud pump flow rate)

• HW NMPC controls the BHP within +/- 1 bar for pipe connection, as opposed to the +/- 20 bar deviation with the PID controller

• HW NMPC attenuates a kick within 1 minute and quickly stabilizes the BHP
Acknowledgements

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Questions Welcome