Welcome to the

SPE-GCS Drilling Study Group

March 17th 2022 Meeting
Thank you Sponsor

SPE-GCS Drilling Study Group
The SPE-GCS conferencing software being used allows meeting hosts and other authorized users to record conference sessions. Part or all of this conference session may be recorded by the host and/or other authorized persons, and your participation in this conference shall constitute your consent to the recording of this conference session.

SPE holds itself and its members to the upmost ethical standard. Event registrants are not authorized to record or distribute the event, nor any sections of it.
Webinar Etiquette

Please remember to “mute” yourself and turn off your web cam.

Please use “Chat” to send your questions.

The moderator will review the questions and pass them to the speaker.
Paul Pastusek is a Drilling Mechanics Advisor at ExxonMobil.

His expertise is in: automation, rig instrumentation and control systems, drill string dynamics, steerable systems, borehole quality, bit applications, cutting mechanics, and failure analysis.

He received the 2020 SPE International and 2017 Gulf Coast Drilling Engineering Awards. He will be giving a series of Distinguished Lecture talks on Rig Control Systems in the 2022-2023 season. (This is a preview.)

Paul has a BSME from Texas A&M University and a MBA from the University of Houston. He has 44 years' experience redesigning drilling processes and tools to the economic limit. He is a Registered Professional Engineer, holds 42 US patents, and has delivered 55 papers and presentations on drilling technology.

He is currently leading two industry efforts: Upgrading the IADC Dull Code and founding the Open-Source Drilling Community.
Primary funding is provided by

The SPE Foundation through member donations and a contribution from Offshore Europe

The Society is grateful to those companies that allow their professionals to serve as lecturers

Additional support provided by AIME
Drill Rig Control Systems:
Detecting Auto Driller Dysfunction and Improving Behavior

Paul Pastusek

ExxonMobil
Outline

• Physics of Stick Slip
• Why should we care about rig control systems?
• Detecting Dysfunction
• Model of Drilling Process and Controller
• Managing Torque Limits
• Detection Take Aways
• Conclusions
Physics of Stick Slip

- Torsional oscillation - winding and unwinding of the drill pipe
- Stick slip - downhole RPM goes to zero
- Often described as a self-excited limit cycle

![Stick-Slip Limit Cycle Graph](image)

![Stribeck Friction Curve Graph](image)
Physics of Stick Slip – A More Complete Explanation

Details
- Shear of the fluid between the pipe and hole
- Striebeck friction of the pipe and BHA
- Torque of the bit due to penetration per revolution

Stick slip can be a limit cycle - self excited by friction
Can be driven by WOB, ROP, RPM variation
Why should we care about drill rig control systems?

- Rig control systems affect stick slip
  - Auto drillers
  - Top Drive Controllers
  - Heave Compensation Systems
  - Pumps, Flow, and Downlinking
  - Power Systems
  - Automation Systems

- Variation
  - Weight on Bit (WOB) $\rightarrow$ ROP $\rightarrow$ Torque $\rightarrow$ Stick slip
    - Bit stalls
    - Motor stalls
    - Top drive stalls
    - Lateral vibration
Auto Driller Theory

- Auto drillers control the drum rotation rate
- In Rate of Penetration (ROP) mode:
  - It directly controls drum speed
  - WOB will vary as rock strength changes
  - ROP will be smooth
  - ROP control is not adding noise

The slope of the WOB/ROP line is determined by the formation and drilling process.

![Diagram showing the relationship between WOB and ROP with different formations (Soft and Hard) and the ROP Set Point.](image-url)
Auto Driller Theory

- Auto drillers control the drum rotation rate

- In ROP mode:
  - It directly controls drum speed
  - ROP will be smooth
  - WOB will vary as rock strength changes

- In WOB mode:
  - If WOB is low → increase drum rotation rate
  - If WOB is high → decrease drum rotation rate

- The step size is determined by the controller
  - Bang-bang or On-off Controller
  - Proportional-Integral-Derivative (PID) Controller
    - Actually PI only is used due to noise in the derivative
  - Model Predictive Controller (MPC)
  - Multiple variations used on drill rigs
Auto Driller Practice: PI Controller

- The step size for ROP is determined by the PI controller
  - P – Proportional to error, I – adjust for the integral error with
  - \[ \Delta ROP = \frac{WOB_{error}}{WOB_{range}} \times P_{gain} \times ROP_{range} + \text{Integral term} \]
  - Stability depends on the P and I values
  - When gain is too high it behaves as if it is a bang-bang controller
  - The controller must also use the correct ranges
  - i.e. \[ \frac{ROP_{range}}{WOB_{range}} \] equals the slope of the ROP/WOB line
What affects the WOB/ROP relationship?

- Hole Size - 24 inch to 6 inch 4:1
- Formation Hardness - 45 ksi to 3 ksi 15:1
- Rotary Speed - 240 RPM to 60 RPM 4:1
- Bit Design – PDC to Roller Cone 5:1

This relationship can change by a factor of 200+ in a well.

Since the relationship between WOB and ROP is not fixed:

- Gains needs to be adjusted
- Some auto drillers do not have rig site adjustment
- Documentation does not cover diagnosis and adjustment
- Work with contractors and OEM vendors on upgrades and training
- Model system prior to deployment
Detecting Dysfunction - Good ROP Control no Dysfunction
Detecting Dysfunction – Stick Slip Driven by WOB Controller

![Diagram showing response tuning and auto driller settings with various parameters displayed.](Image)

- **EMERGENCY-STOP**
  - ENGINE
  - VFD
  - DRAWWORKS
  - TOPDRIVE
  - MUD PUMP

- **Generators**
  - Online: 2
  - Load: 0

- **Rectifiers**
  - Online: 2
  - Voltage: 794 Vdc

- **Dynamic Brake**
  - Online: 4
  - Load: 0

- **Em Brake**
  - Status: Released
  - Pressure: 1.314 psi

- **Park Brake**
  - Status: Released
  - Pressure: 9 psi

- **Dw HPU**
  - Pressure: 1,523 psi

- **Rig Hyd**
  - Pressure: 8 psi

- **Rig Air**
  - Trip Tank
  - Pressure: 121 psi

- **Response Tuning**
  - HOIST: 1
  - WOB: 0.20
  - TORQUE: 1.00
  - DELTA P: 1.00

- **Auto Driller**
  - Auto Drill
  - WOB
  - TORQUE
  - DELTA P

- **5 Minute Trend**
  - Graph showing data trends over a 5-minute period.
Improving Behavior - Tuning the Proportional Gain
Improving Behavior – Modeling the Process and Controller

Auto Driller Simulation - PI Controller

Drilling Process
- Gain (G): 2
- Time Constant (T): 2
- Delay (D): 2
- CCS (ksi): 10
- CCS Var (Random): 25%

Controller
- P Proportional (K): 2.00
- I Integral (Ti): 2.00
- D Derivative (Td): 0.00
- Pick Up %: 10%

RPM
- RPM Set Point: 80

Enable WOB Controller
- ROP Set Point: 250
- WOB Set Point: 45
- Control Gain: 10
- Pick Up %: 10

Rate of Pen (ft/hr)

WOB (k lb)

Time (sec) - 5 Minute Window
Improving Behavior – Training Drillers to Tune the Gain

Rig Poster

• Gain Too Low long response time

• Gain Just Right fast response, tracking well

• Gain Too High or ROP Setpoint Too High overshoot, “painting the screen”
Improving Behavior - Automatic Tuning
Auto Driller Theory - Multiple Loops In Control

- ROP Set Point
  - ROP Sensor
  - Drum Speed Minimum of all Inputs
  - PID* Loop
  - Need Bumpless Transfer between loops

- WOB Set Point
  - Hook Load Sensor
  - PID* Loop

- Differential Pressure SP
  - Stand Pipe P Sensor
  - PID* Loop

- Torque Limit
  - Torque Sensor
  - Stop Drum

*PID - Proportional-Integral-Derivative controller
Top Drive Stalling Reinforces Stick Slip

Drill Collar RPM

Top Drive RPM

Why did the increase in RPM not affect stick slip?

Top Drive Torque (kft lb)

Time (Hr:Min)

5 Minutes
28 Peaks

= 10.7 sec stick slip period
Detection Take Aways

If drum rotation is not smooth and continuous, or any parameters ‘paint the screen’ or have a regular pattern, we have an opportunity

**Must determine the root cause**
- Self Induced Stick Slip
- Auto Driller Driven
- Torque Limit Driven
- Heave, Downlinking, etc.

**Stick slip not Auto Driller driven when**
- Off Bottom
- When in ROP mode
- Reduced with clean up cycle
Conclusions

- Some dysfunctions are self imposed
- Multiple rig control systems can excite and/or drive stick slip
- The auto driller can have a major impact on system stability
- Some auto driller systems must be upgraded to get access to tuning
- Managing torque limits is essential to improving system stability
- Crew training and tuning can substantially improve performance
- Automation systems add another layer of complexity to the controllers
- The base system must be stable before automation
- Modeling the system with multiple SMEs is required to reduce dysfunctions
- Modeling can and should be applied to most control systems.
Q & A
Your Feedback is Important

We will email it to you
# Upcoming Webinars (11:30 AM – 1 PM)

<table>
<thead>
<tr>
<th>Date</th>
<th>Venue</th>
<th>Theme</th>
</tr>
</thead>
<tbody>
<tr>
<td>21-Apr-22</td>
<td>Hybrid Petroleum Club</td>
<td>“U.S. Energy Policy - the Good, the Bad, and the Ugly” by Mr. Wesley Hunt, candidate for U.S. Congressional District 38</td>
</tr>
<tr>
<td>5-May-22</td>
<td>Hybrid Petroleum Club</td>
<td>“Drilling Technology Research Overview” by Dr. Ozbayoglu, University of Tulsa</td>
</tr>
</tbody>
</table>
Stay in Touch

Update your email preferences to hear from your favorite study groups and committees in the SPE Gulf Coast Section

http://spe-gulfcoast.informz.net/spe-gulfcoast/default.asp?fid=3590
Please remember to update your email preferences so that you are getting all of the emails for the various study groups/committees using this link:

Using the GCS Website (Option 1)

Main Page spegcs.org ➔ Member Resources ➔ Stay in Touch ➔ Click here to Update Email Preferences
Please remember to update your email preferences so that you are getting all of the emails for the various study groups/committees using this link:

Using the GCS Website (Option 2)

http://spe-gulfcoast.informz.net/spe-gulfcoast

Main Page spegcs.org → Events & News→ Update Email Preferences