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SPE-GCS Drilling Study Group

March 17th 2022 Meeting

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A screenshot of a chat interface. At the top, it says "Enter your message". In the center, the text "Type Question Here" is written in red. At the bottom, there is a "Send to" dropdown menu with "Everyone" selected and a "Send" button partially visible on the right.

Today's 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.

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Drill Rig Control Systems: Detecting Auto Driller Dysfunction and Improving Behavior

Paul Pastusek

ExxonMobil



Society of Petroleum Engineers

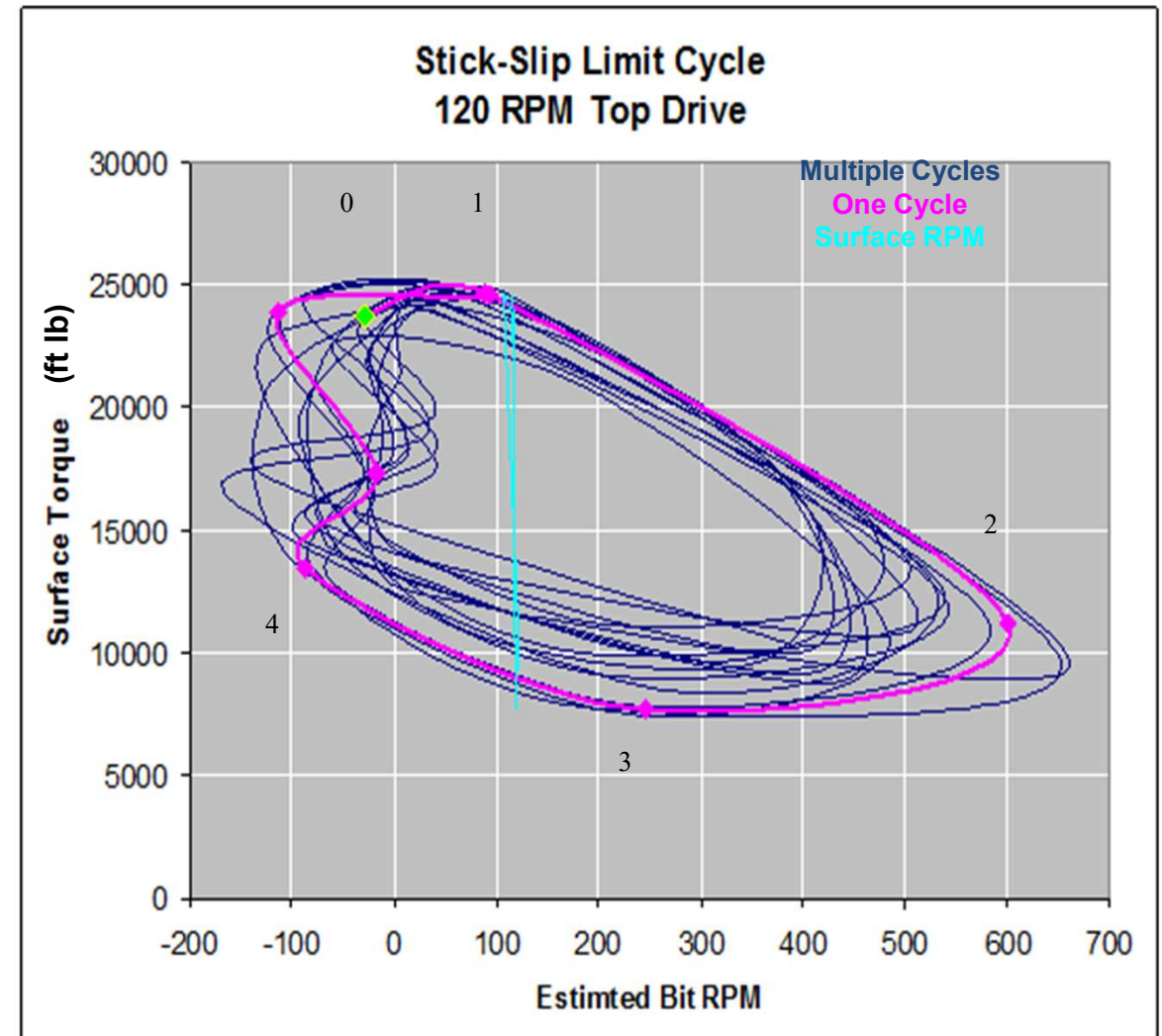
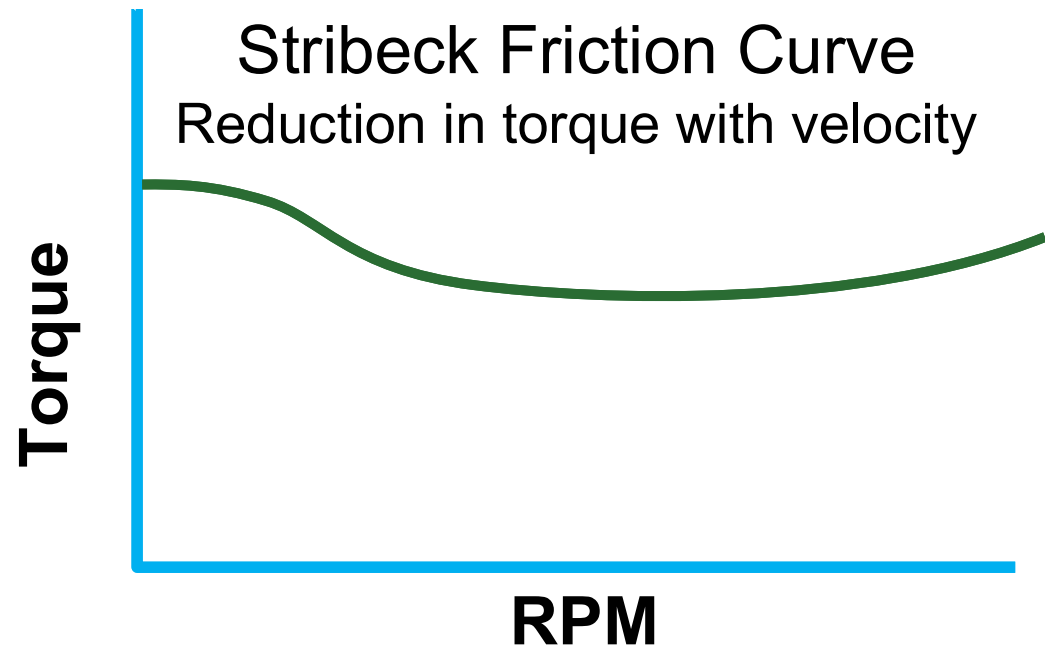
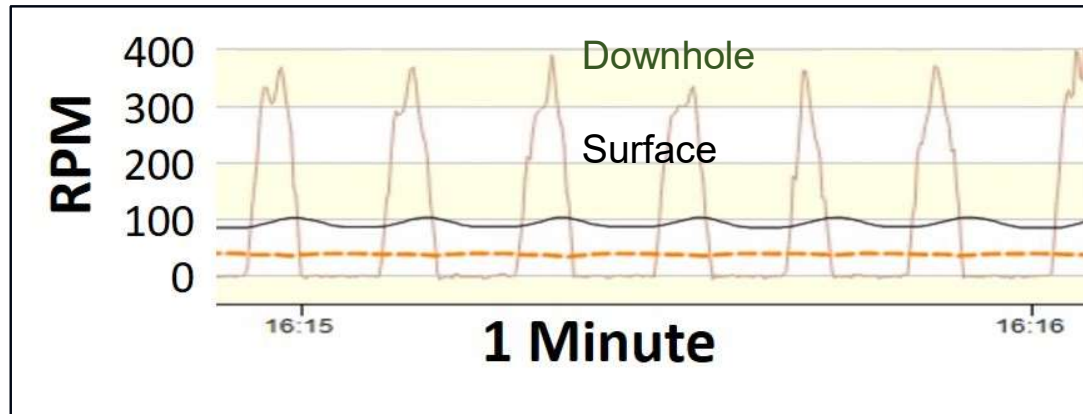
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Outline

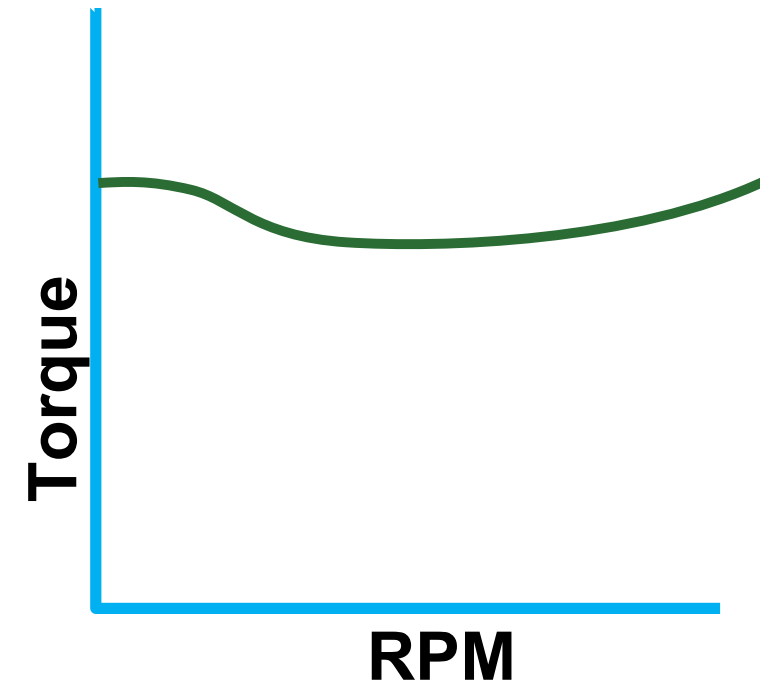
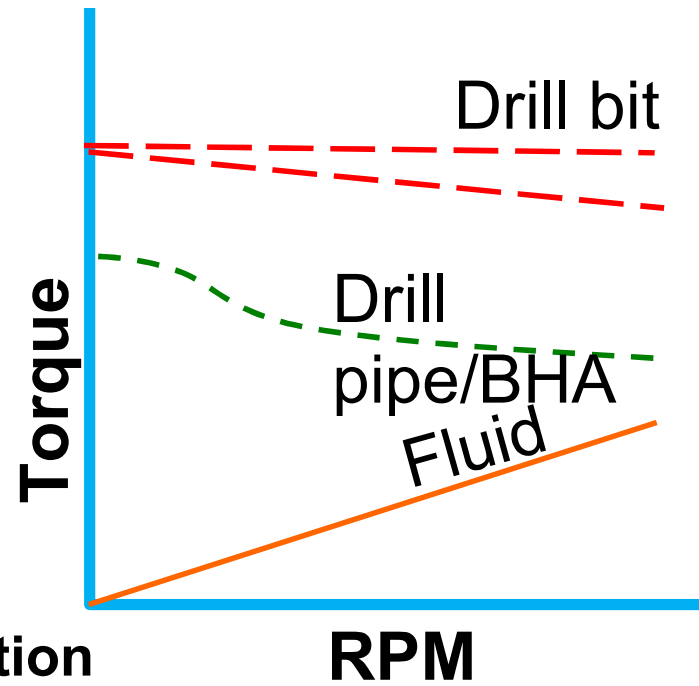
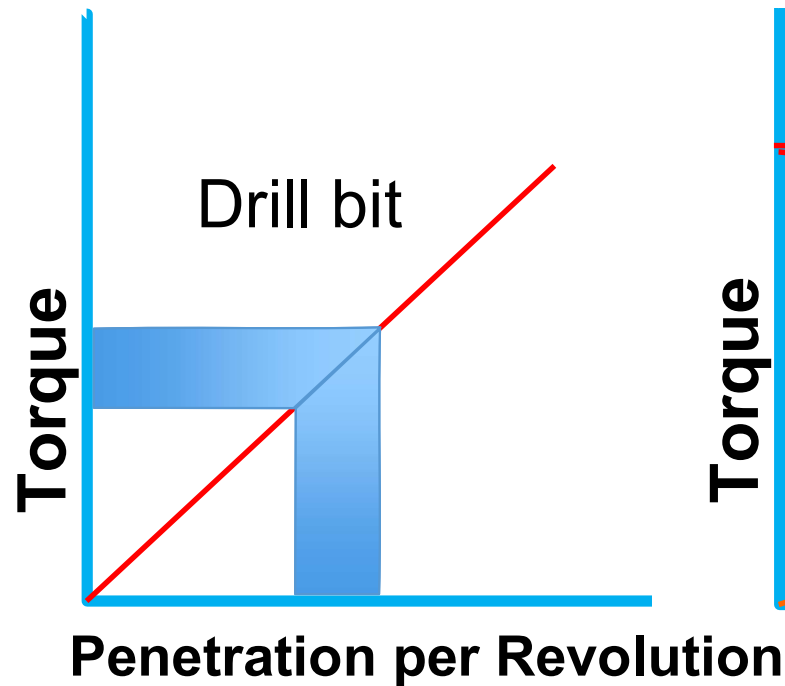
- Physics of Stick Slip
- Why should we care about rig control systems?
- Detecting Dysfunction
- Model of Drilling Process and Controller
- Managing Torque Limits
- Detection Take Aways
- Conclusions

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



Physics of Stick Slip – A More Complete Explanation



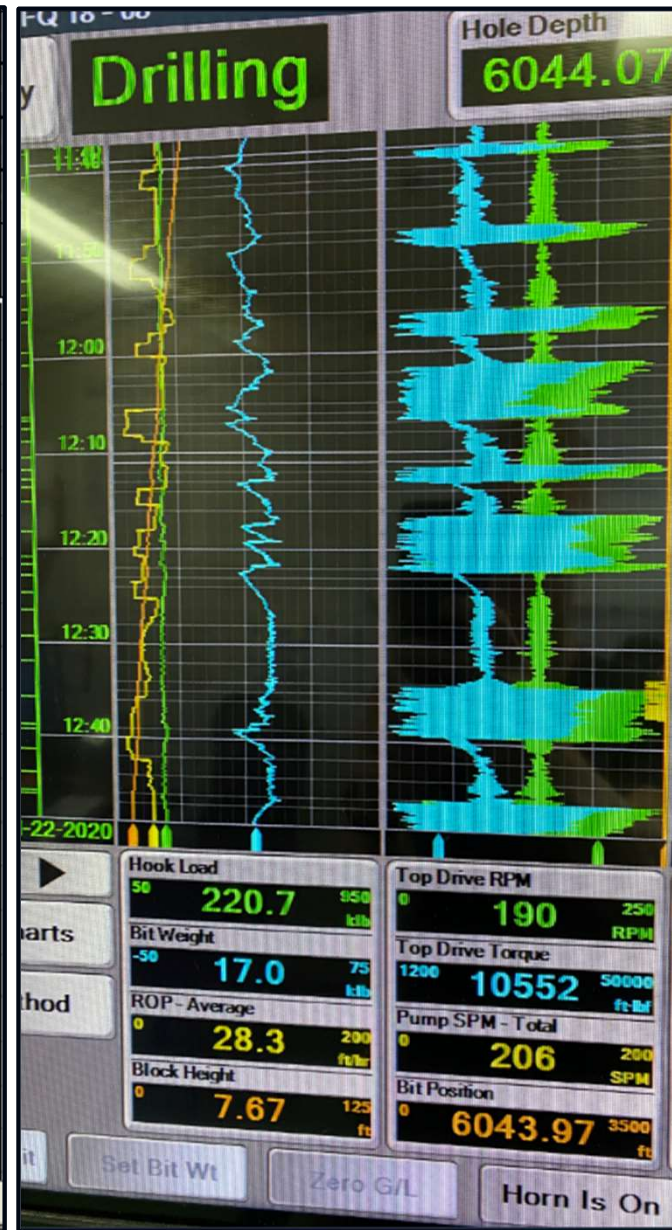
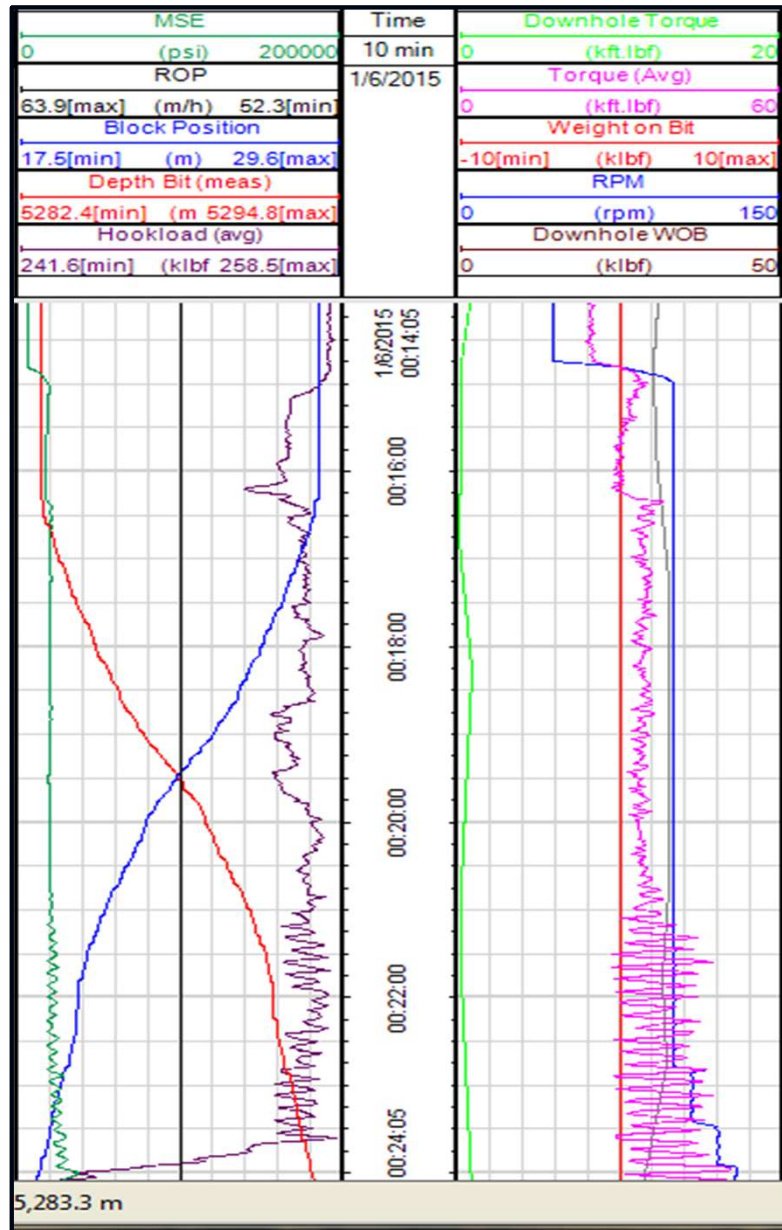
Details

- Shear of the fluid between the pipe and hole
- Stribeck 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) → ROP → Torque → Stick slip
 - Bit stalls
 - Motor stalls
 - Top drive stalls
 - Lateral vibration

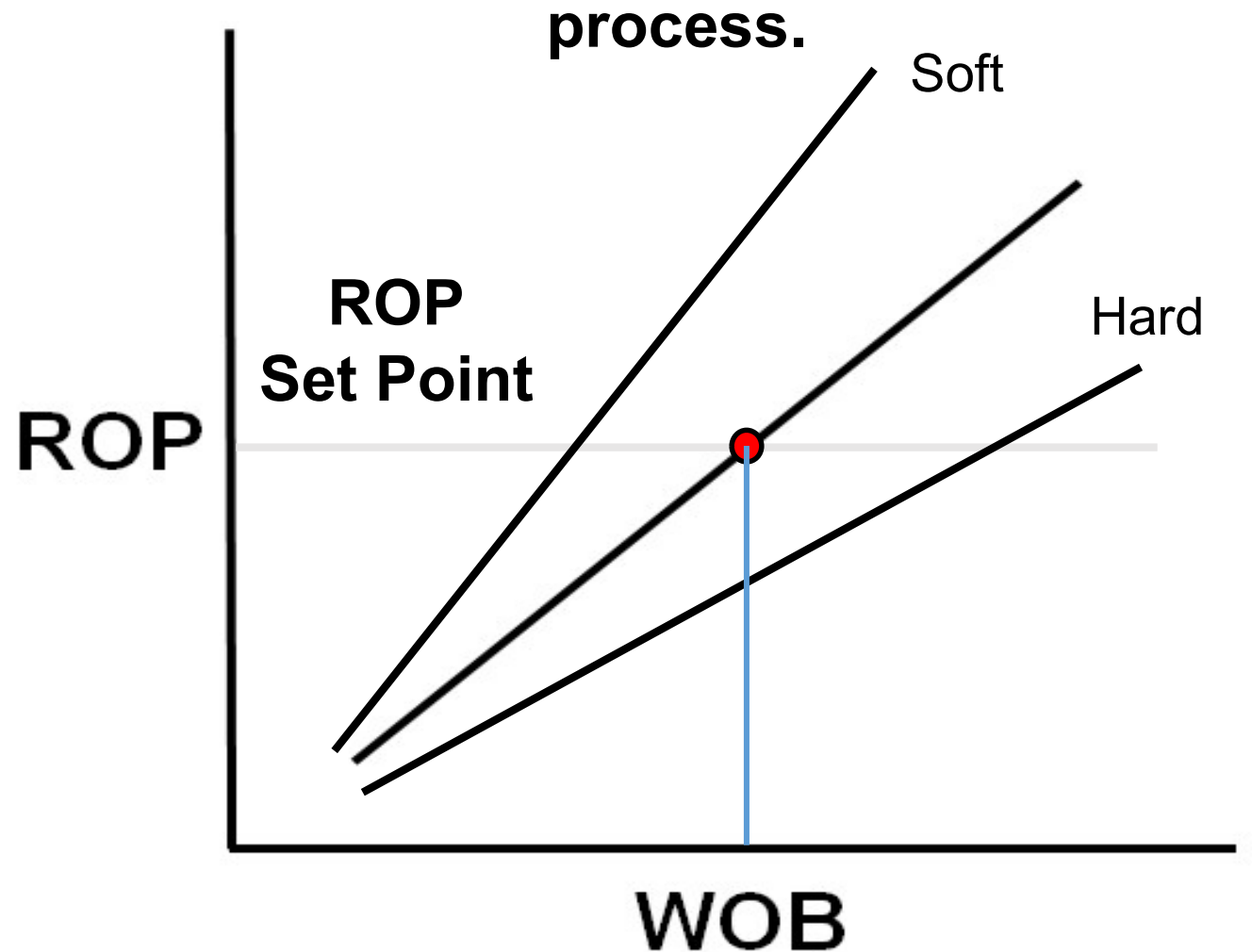
Coupled Stick Slip and WOB Variation

Stick Slip without WOB Variation

Auto Driller Theory

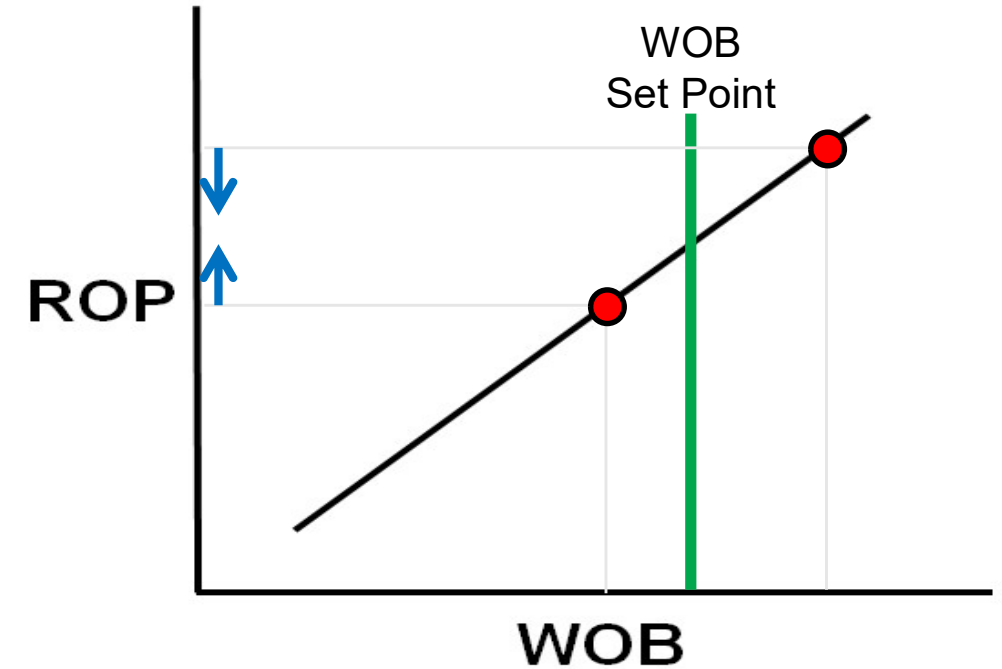
- Auto drillers control the drum rotation rate
- In Rate of Penetration (ROP) mode:
 - It directly controls drum speed
 - WOB will vary as rock strength changes
 - ROP will be smooth
 - ROP control is not adding noise

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



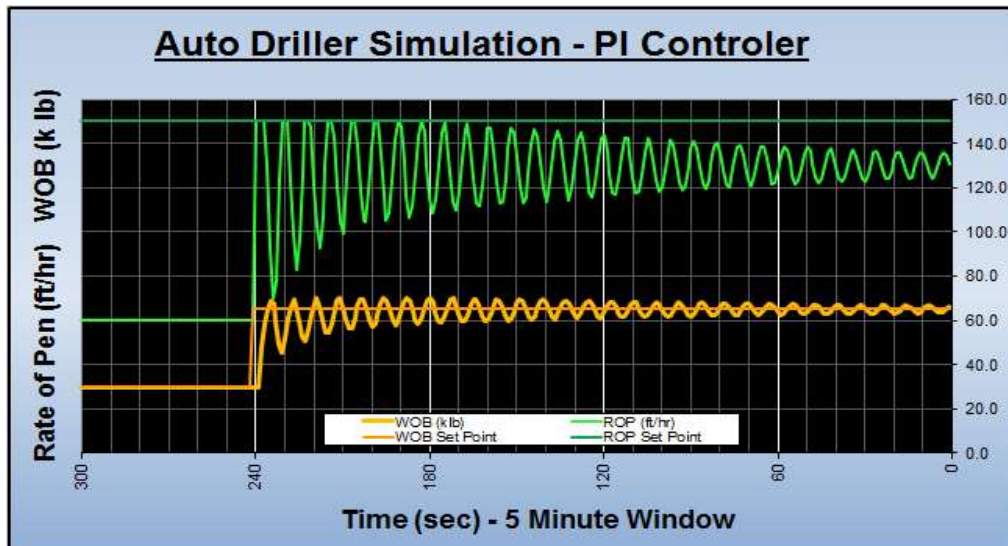
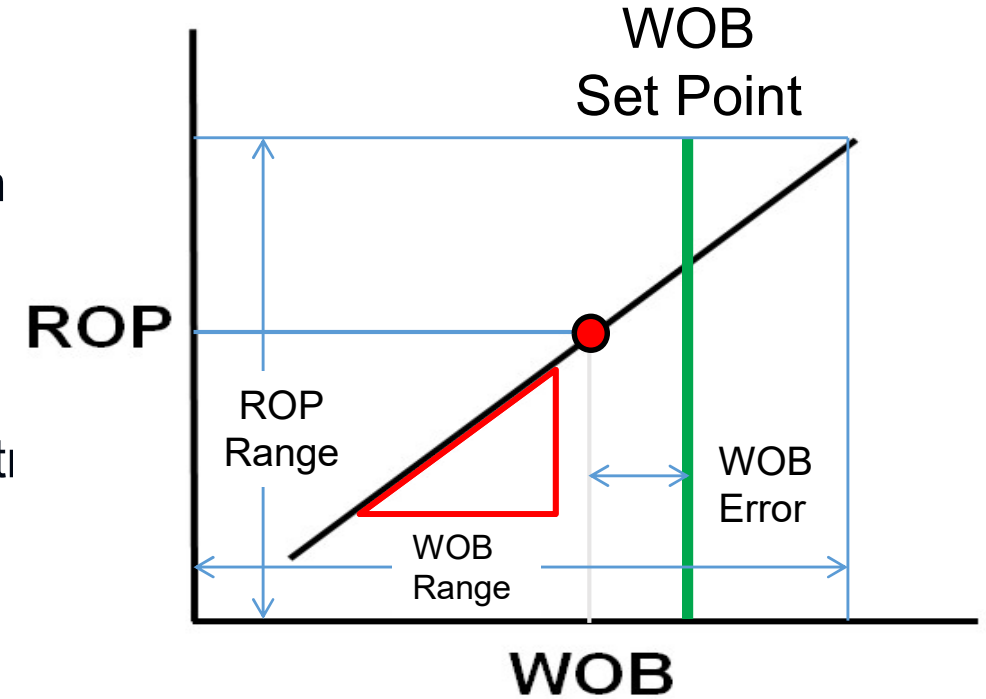
Auto Driller Theory

- 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

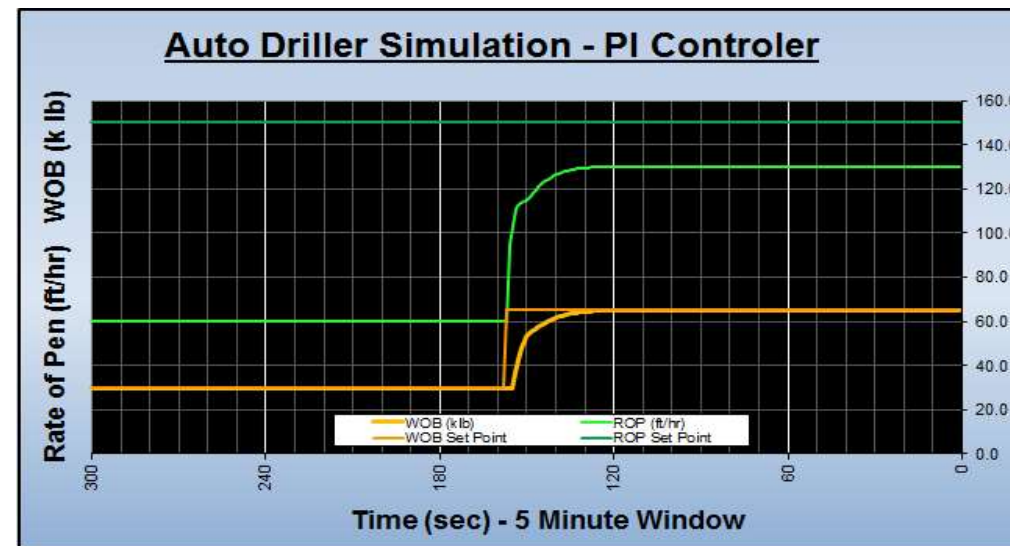
- The step size for ROP is determined by the PI controller
 - P – Proportional to error, I – adjust for the integral error with
 - $\Delta ROP = \frac{WOB_{error}}{WOB_{range}} * P_{gain} * ROP_{range} + \text{Integral term}$
 - Stability depends on the P and I values
 - When gain is too high it behaves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



Gain Too High

ROP

WOB



Gain Just Right

ROP

WOB

Drilling System Response - Tuning & Re-tuning the System

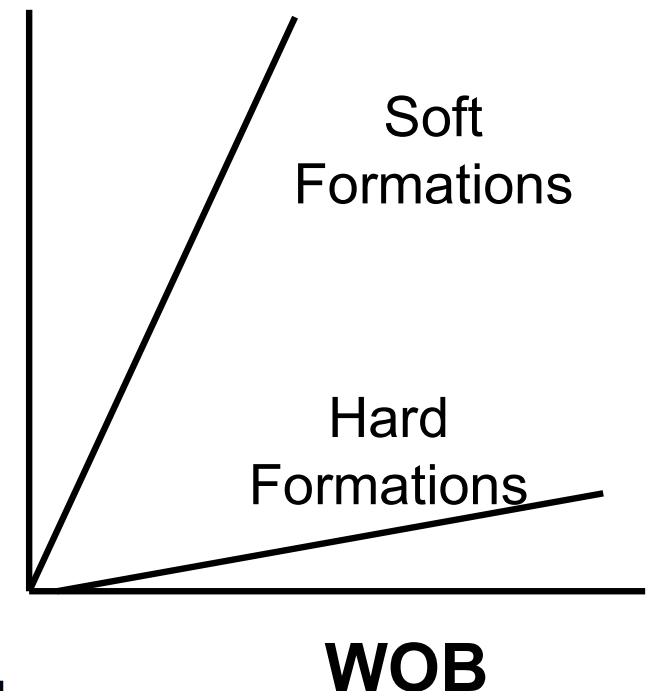
- **What affects the WOB/ROP relationship?**

- | | |
|--|------------|
| ● Hole Size - 24 inch to 6 inch | ROP
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 |

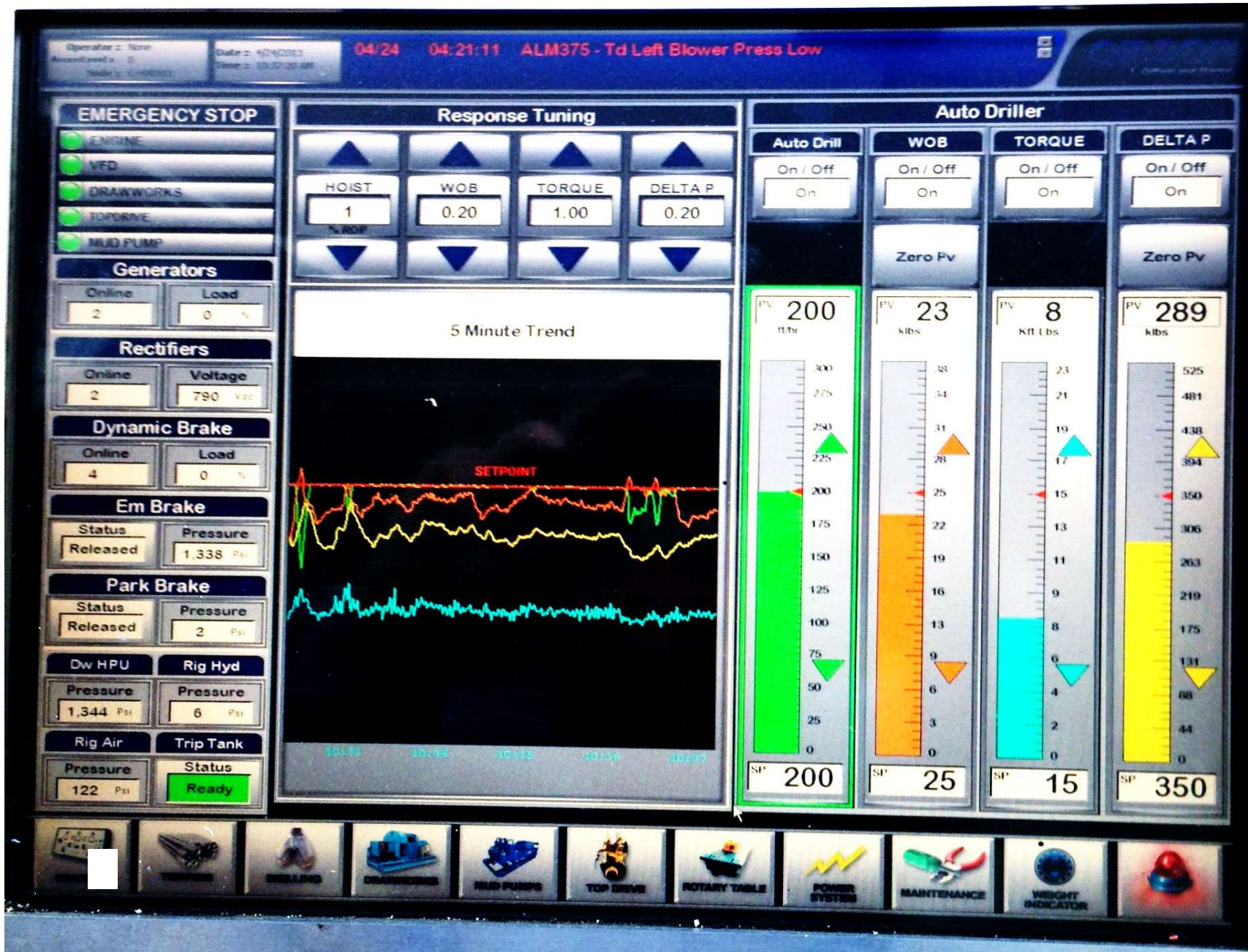
- **This relationship can change by a factor of 200+ in a well**

- **Since the relationship between WOB and ROP is not fixed**

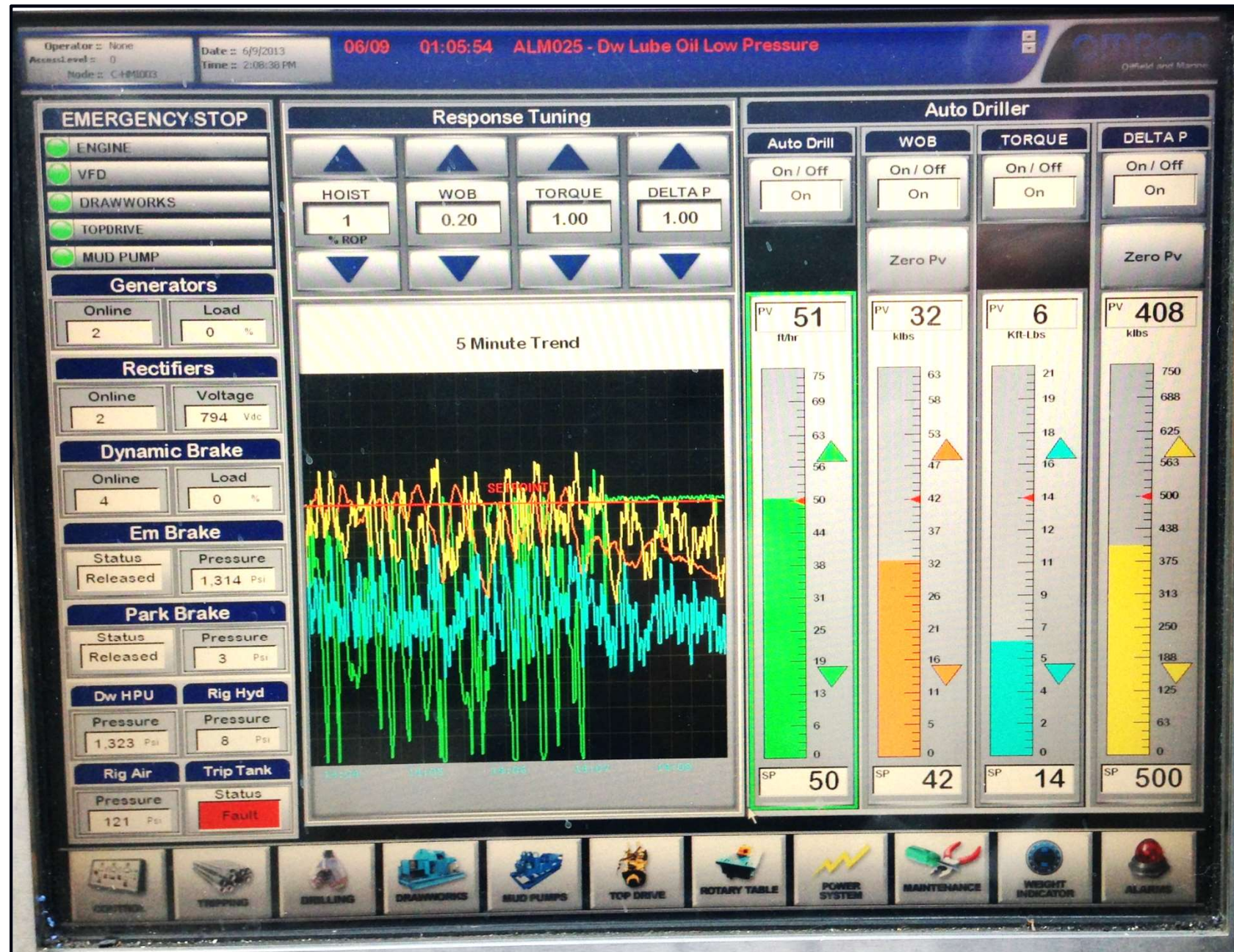
- Gains needs to be adjusted
- Some auto drillers do not have rig site adjustment
- Documentation does not cover diagnosis and adjustment
- Work with contractors and OEM vendors on upgrades and training
- Model system prior to deployment



Detecting Dysfunction - Good ROP Control no Dysfunction



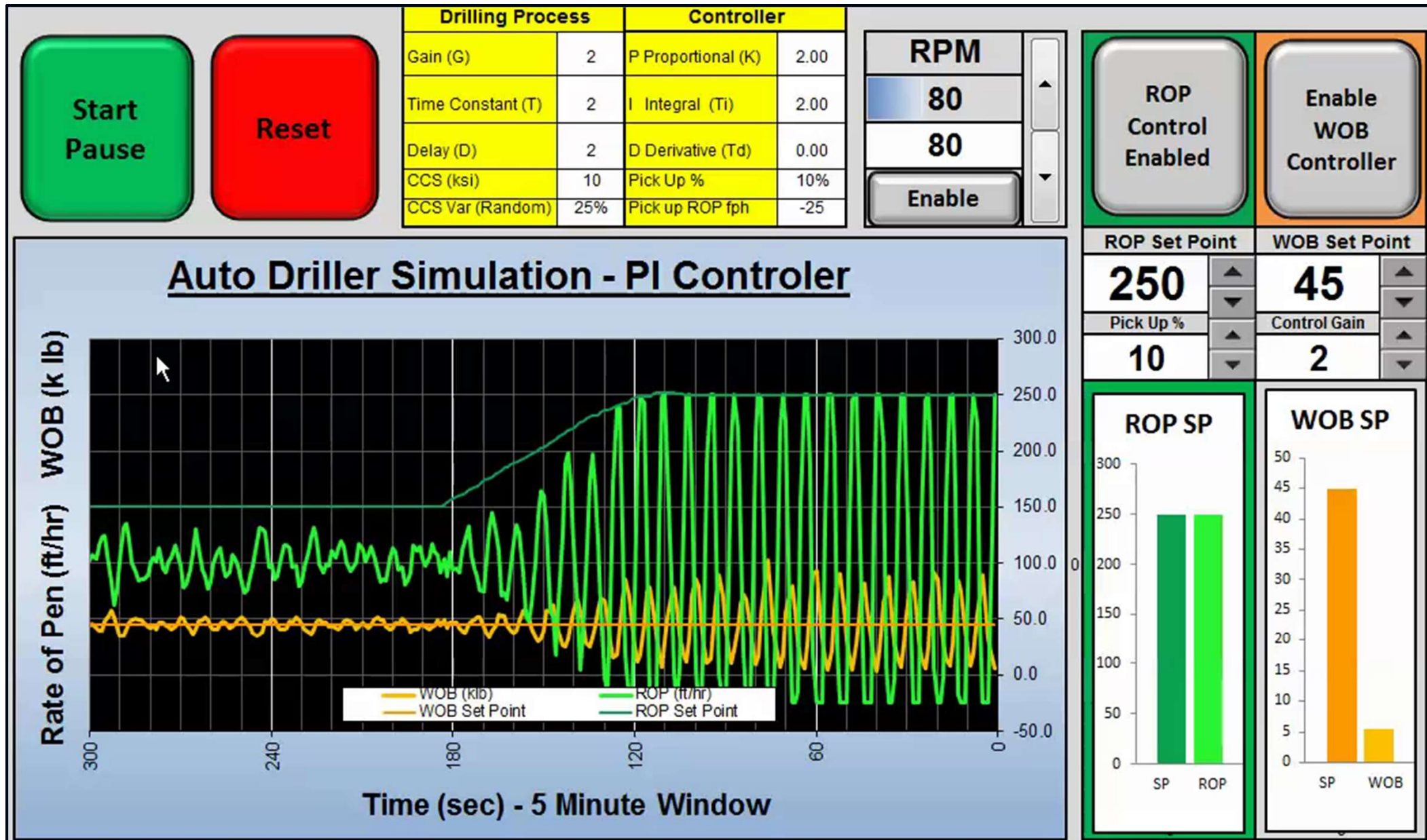
Detecting Dysfunction – Stick Slip Driven by WOB Controller



Improving Behavior - Tuning the Proportional Gain



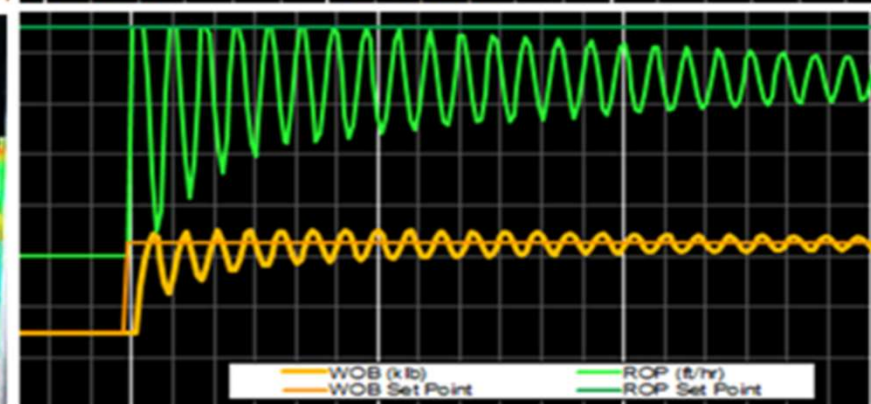
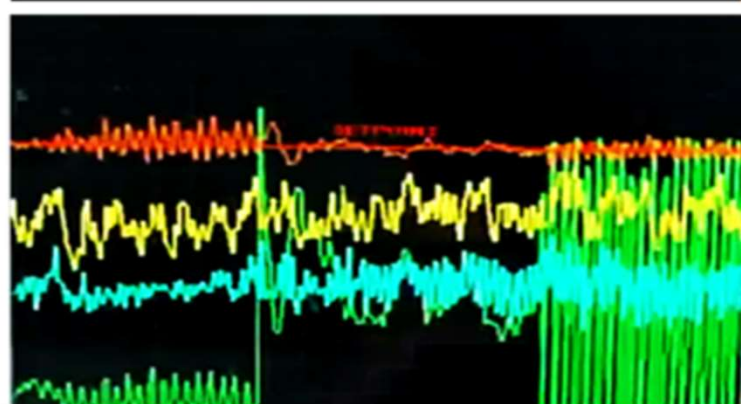
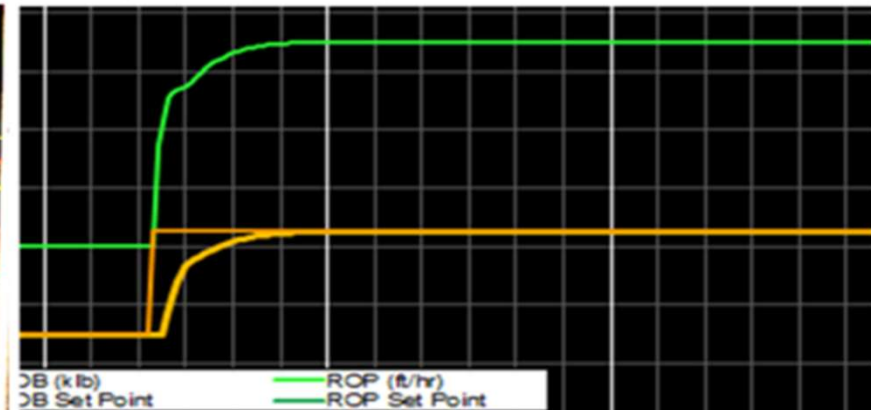
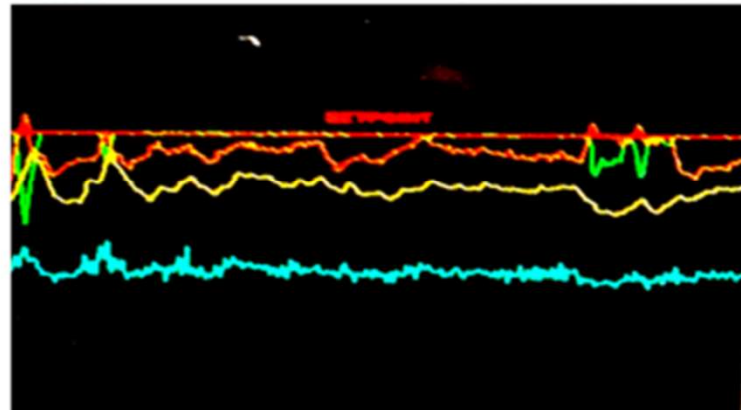
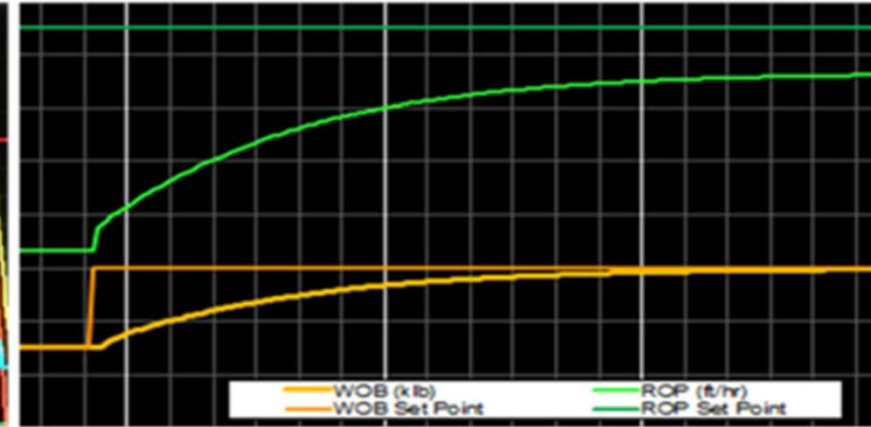
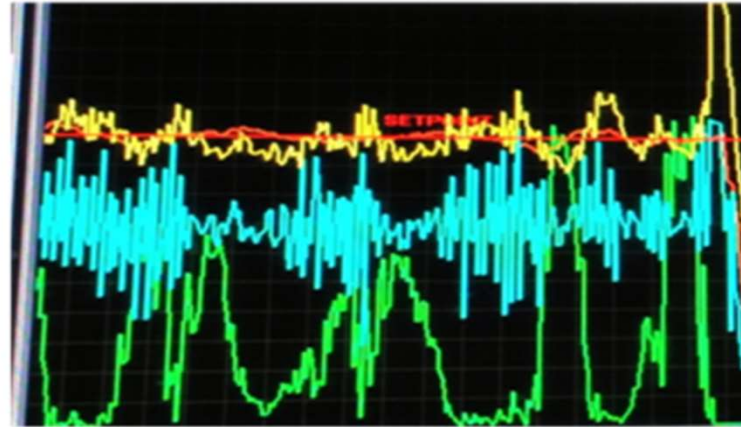
Improving Behavior – Modeling the Process and Controller



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

Start
Pause

Reset

Drilling Process		Controller	
Gain (G)	2	P Proportional (K)	0.41
Time Constant (T)	2	I Integral (Ti)	2.00
Delay (D)	2	D Derivative (Td)	0.00
CCS (ksi)	10	Pick Up %	10%
CCS Var (Random)	25%	Pick up ROP fph	-25

RPM

80

80

Enable

ROP
Control
Enabled

Enable
WOB
Controller

ROP Set Point

250

Pick Up %

10

WOB Set Point

45

Control Gain

0.3

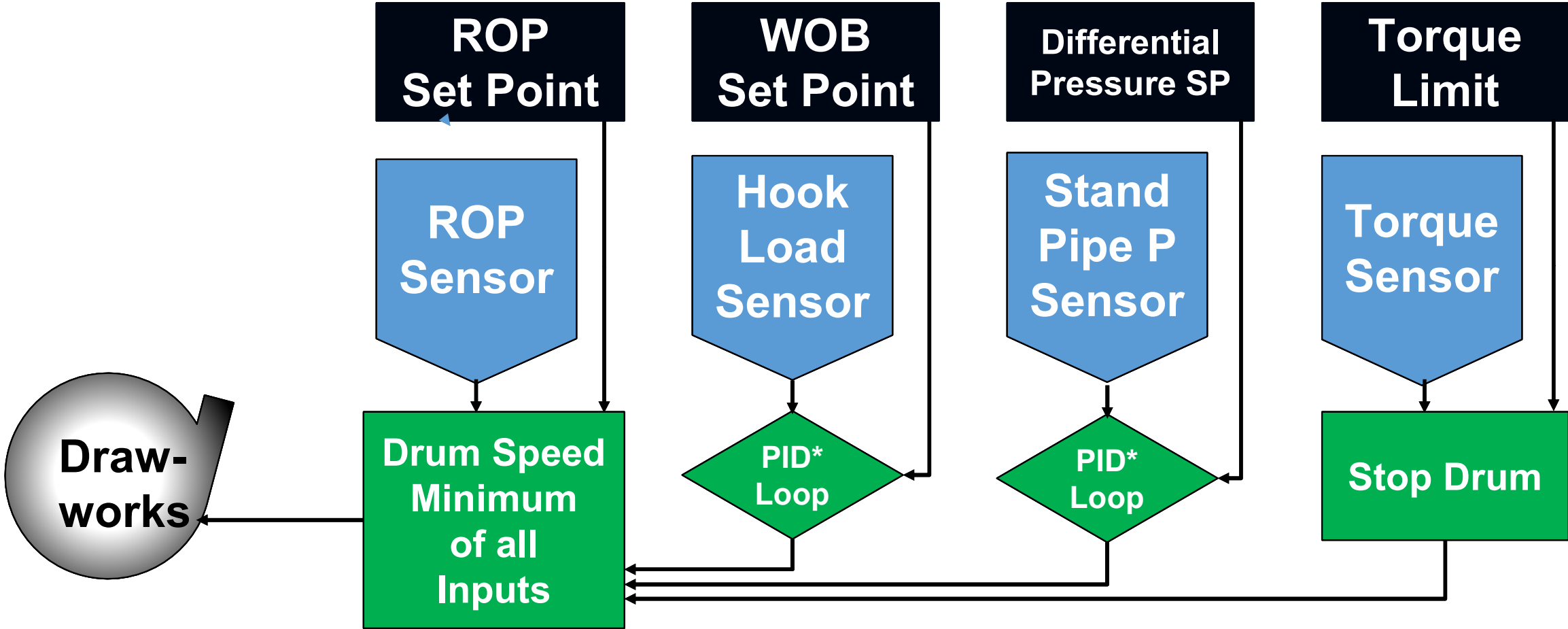
ROP SP

WOB SP

Auto Driller Simulation - PI Controller

Time (sec) - 5 Minute Window

Auto Driller Theory - Multiple Loops In Control

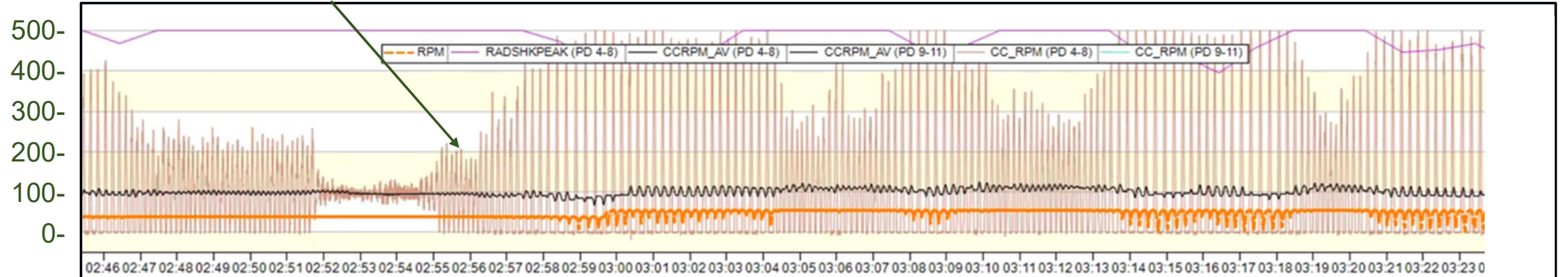


Need Bumpless Transfer between loops

*PID - Proportional-Integral-Derivative controller

Top Drive Stalling Reinforces Stick Slip

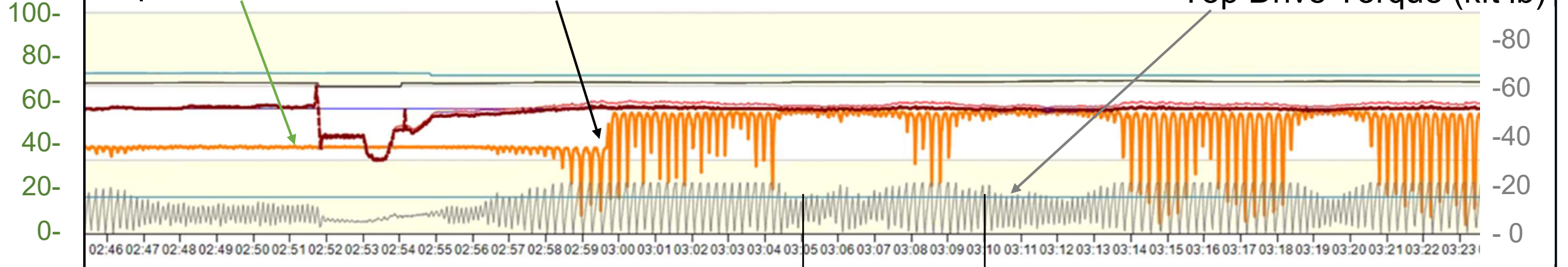
Drill Collar RPM



Top Drive RPM

Why did the increase in RPM not affect stick slip?

Top Drive Torque (kft lb)



Time (Hr:Min)

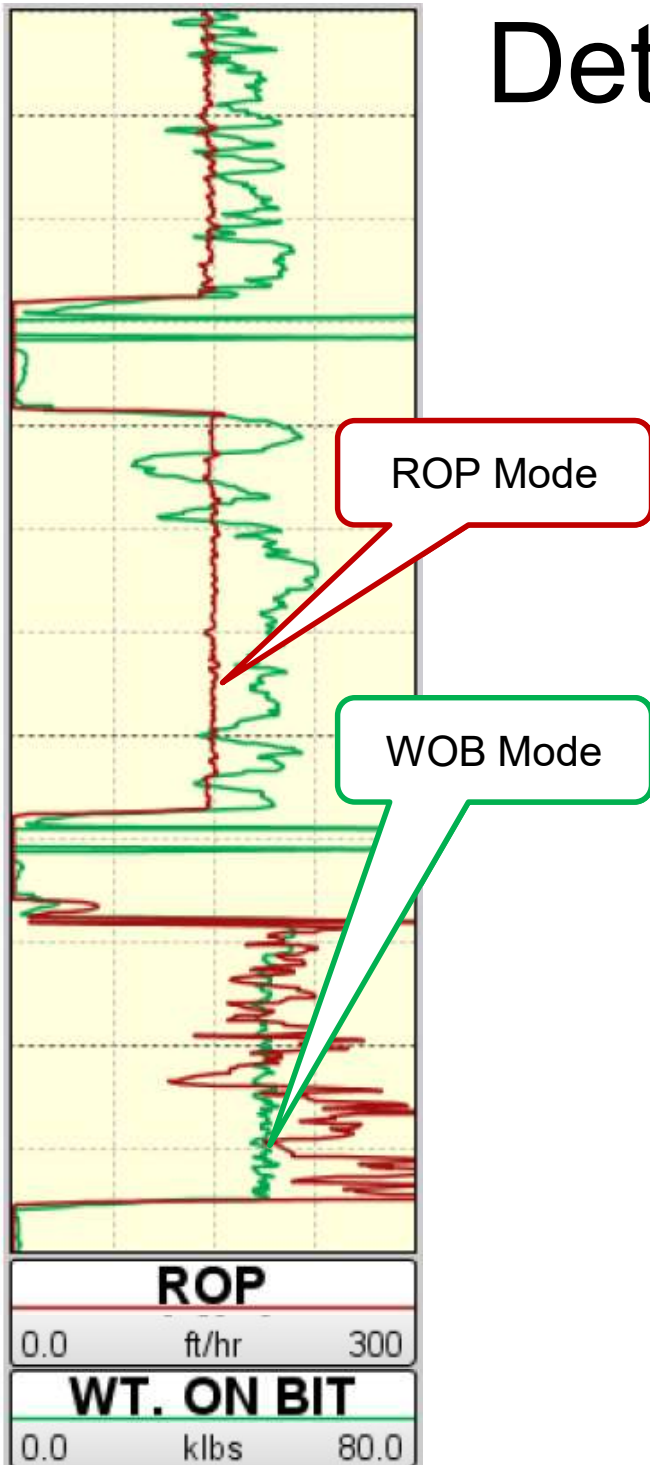
5 Minutes

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



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Upcoming Webinars (11:30 AM – 1 PM)

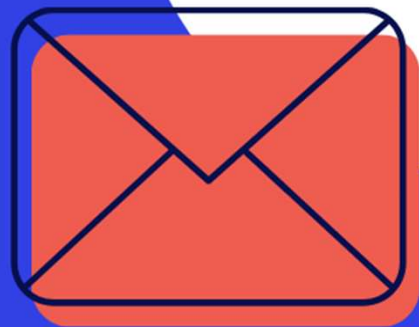
<u>Date</u>	<u>Venue</u>	<u>Theme</u>
21-Apr-22	Hybrid Petroleum Club	“U.S. Energy Policy - the Good, the Bad, and the Ugly” by Mr. Wesley Hunt, candidate for U.S. Congressional District 38
5-May-22	Hybrid Petroleum Club	“Drilling Technology Research Overview” by Dr. Ozbayoglu, University of Tulsa



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A screenshot of a web browser displaying the SPE Gulf Coast Section website. The browser tabs show 'SPE-GCS | Society of Petroleum E...', 'Member Resources | Houston, Te...', and 'Welcome'. The address bar shows 'spegcs.org/member-resources/'. The website header includes the SPE Gulf Coast Section logo, navigation links for 'EVENTS & NEWS', 'PROFESSIONAL DEVELOPMENT', 'STUDY GROUPS', 'OUR COMMITTEES', 'YOUNG PROFESSIONALS', and 'ABOUT US', and a 'DONATE' button. The main content area is titled 'Member Resources' and features a 'Treasury' section with a list of links: 'Nexonia How-To', 'Treasury Event Report Form', 'Pulling An Event Roster Report', 'Tax Exempt Form 2021', 'Invoice Template', 'W9 2021', and 'Refund Policy'. To the right, there is a 'Stay in Touch' section with the text 'Update your email preferences to hear from your favorite study groups and committees in the SPE Gulf Coast Section.' and a prominent blue 'Sign Up Now' button.

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A screenshot of the website's navigation menu. The 'EVENTS & NEWS' menu item is circled in red. Underneath it, the 'Update Email Preferences (SPEI members only)' link is also circled in red. The menu includes sections for Events, Hiring Event, and Stay Connected.

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