Update on DWD
(Diagnostics-While-Drilling)

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Diagnostics-While-Drilling: What is it?

DWD is a closed-loop, high-speed, real-time data system between the surface and downhole. The first application focuses on bit dynamics, as an adjunct to Sandia’s PDC bit program.
What is “high-speed” data?

- Mud-pulse - 2-10 bits/second (baud)
- EM through earth - <10 baud
- Drillstring acoustic - 1-1000 baud (depth dependent)
- Conventional wireline - >200 k-baud
- Wet-connect - >200 k-baud (demonstrated)
- Optical fiber - >>100 k-baud
- Wired pipe - TBD
Prototype system

Measurement sub – acquires, conditions, and transmits downhole sensor data

Data Link - carries information and control signals between surface and downhole

Instrumented Drill Rig – provides for display and archive of surface drilling data

Driller’s Display - displays selected set of real-time, high-resolution data from both downhole and surface. Display can be either raw or processed (FFTs, etc.) data.

Driller – experienced driller with engineering background can use more sophisticated display than traditional console.
DWD measurement sub

- 3-axis plus angular accelerometers
- WOB, TOB, Bending strain gauges
- Magnetometers (rotary speed)
- Internal/external pressure
- Internal/external temperature
Wet-connect wireline
(make and break electrical connection in mud)

- Electrical swivel allows rotation of lower wireline relative to upper
- Allows power to tool from surface (no batteries)
- Don’t have to trip pipe for wireline service
What the driller sees

Conventional

Digital panel
With DWD
Project roadmap

- Concept
- System definition
- Synthesis with PDC program
- Industry involvement (TAC and workshops)
- Preliminary testing
- Drilling tests
- Further development
Vibration test set-up

Y-axis test

Z-axis test

Y-axis test
**Objectives / Results**

- Verify accelerometer calibrations / verified for level
- Identify sensitive or resonant frequencies / found resonant dwell frequencies
- Check tool’s ruggedness / found two minor electronic problems that were repaired
Laboratory drill rig
Objectives

- Verify DWD measurements (rotation, etc.) not previously made
- Test ability to identify bit whirl or other dysfunctions using data display
- Check tool’s operation in a semi-realistic environment
- Compare measurement sub values with laboratory data
Data acquired

- Measurement sub: strain gauges (WOB, TOB, BOB), accelerometers, magnetometers
- Laboratory: weight, torque, rotary speed, ROP
- Rock: wellbore profile (smoothness)
Hole profiles

Smooth drilling

Bit whirl
Results

- Most data successfully taken
- Tool operated under realistic drilling loads – up to 50k-lb WOB, up to 150 rpm rotary speed
- Bit whirl identified from a variety of diagnostics
Proof-of-Concept overview

Phase 1 test to take data from a PDC bit drilling through the test interval, but not use data feedback for control.

Phase 2 to compare performance of an identical PDC bit drilling the same interval as Phase 1, but using DWD feedback control in the second test.

That is, does DWD help drilling?
Test plan

Phase 1
Week of 15 July

~ 1100
The Wall

~ 1800

Roller-cone baseline

PDC without DWD control

Baseline data

POC Test

Phase 2
Week of 5 August

Phase 2 hole deviated 10°

PDC baseline

PDC without DWD control

PDC with DWD control
Catoosa Lithology

GRI Catoosa Test Site
(S25 T21N R14E, Rogers Co., OK)

- Big Lime  Surface - 70'
- Peru Sandstone Zone (70' - 277')
- Oswego Limestone (277' - 304')
- Prue Sandstone Zone (304' - 373')
- Verdigris Limestone (373' - 383')
- Skinner Sandstone Zone 383' - 393'
- Pink Limestone (393' - 604')
- Red Fork Sandstone Zone (604' - 828')
- Inola Limestone (828' - 838')
- Bartlesville Sandstone Zone (838' - 879')
- Booch Sandstone Zone (879' - 1188')
- Burgess Sandstone (1188' - 1218')
- Fayetteville Shale (1216' - 1252')
- Mississippi Lime (1252' - 1549')
- Woodford Shale (1549' - 1578')
- Misener Sandstone (1578' - 1605')

Test Interval
Bottom-Hole Assembly

Bit

NBS

XO

DWD
measurement sub

IBS

1 ea 6-1/4” DC

18 ea 6-1/4” DC
Test Bit

- Security-DBS model PD5
- 8-1/2” diameter
- Older design, but refurbished with newer technology cutters
Phase 1 process

Driller had considerable experience at Catoosa

Driller had specific instructions on starting and stopping drilling

Otherwise left to driller’s judgment (WOB, rotary speed)

Record all data

POH for periodic bit inspection

Drill to 1800’ or bit failure, whichever comes first
Phase 2 process

- Same driller as Phase I
- Downhole-data displays in doghouse
- Engineers signal driller, via intercom, to “pick up” or “resume drilling”
- Engineers specify WOB and rotary speed for driller to resume drilling
- Driller uses his initiative to pick up if conditions appear harmful
- POH for periodic bit inspection
- Drill to 1800’ or bit failure, whichever comes first
Results – system performance

- Total drilling with measurement sub – 1400+ feet, 26+ hours – showed no significant problems
- Wireline had intermittent failures but was quickly repaired
- Data acquisition system archived virtually all data
- Data display was very useful in assessing drilling conditions, but is not optimally unified
Results – bit life

Start @ ~ 1100’. First hard stringers @ 1274’, Wall @ 1385’

Phase I: drilled to 1492’ – 392’ total life, 107’ in Wall

Phase II: drilled to 1615’ (ran out of time) – 515’ total life, 230’ in Wall
### Results – rate of penetration

<table>
<thead>
<tr>
<th>Approximate Depth Interval</th>
<th>Rate of Penetration, feet per hour</th>
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<tbody>
<tr>
<td></td>
<td>Phase 1</td>
</tr>
<tr>
<td>1105-1169</td>
<td>105.6</td>
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<td>1169-1233</td>
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<td>1605-1627</td>
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</table>
ROPP and WOB

Phase 1
Phase 2

Rock Strength

10-15 ksi
15-25 ksi
> 25 ksi

Rate of Penetration, ft/hr
Weight on Bit, k-lb

Depth, ft

1000
1100
1200
1300
1400
1500

0 40 80 120 0 10 20 30
Normalized ROP

Phase 1

Phase 2

Rock Strength

10-15 ksi

15-25 ksi

> 25 ksi

Rate of Penetration/Weight on Bit x RPM

Depth, ft

1500

1450

1350

1300

1250

1200

1150

1100

0 4 8 12 16
Conclusions

- Objectives mostly met; system performed well
- Downhole data showed effects not visible at surface
- High-speed, real-time data from downhole is viable, although not field-ready
- Bit dysfunctions can be distinguished
- We made the correct measurements
- There is a learning curve in using this system
Comparison of surface and downhole WOB
Next activity – bit tests

- CRADA with 4 bit companies
- Each company supplied with data from Phase 1 and 2 tests
- Each company will provide “best effort” hard-rock PDC bit
- Drill same interval as POC with each bit
- Each company provides drilling engineer for its test
Near-term objectives

- Other formations, other bits
- Different BHAs
- Unify data displays
- Better data processing and analysis
- High-temperature tool
- Industry involvement
DeepTrek solicitation

“Improved Economics in Deep-well Drilling”

Needs for field-ready system

- Alternate data link
- Optimum data rate
- Driller’s display