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An Instrumented Topdrive Sub System: Enabling Greater Drilling Efficiencies via Innovative Sensing Capabilities

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Surface Drilling Mechanics System

Rigfloor Computer

Topdrive

Topdrive

Sub

RF Comms Module, with Antennas

Ethernet LAN to EDR

RS-232 to 3rd Party

Driller's Doghouse

Uplink Task Tables, Downlink Data Streams

Class 1, Div 2 or Safe Area

Class 1, Div 1 Area

Topdrive

Topdrive Sub

RS-232 to 3rd Party
Why?

- Many rig surface sensor systems:
  - Utilize indirect measurements
  - Possess sensors that are inaccurate, not regularly maintained
  - Have sensors with missing or no calibration credentials
  - Fixed sampling rates
  - Do not identify measurement quality
  - Use EDRs that have high latency times

- These factors impede drilling efficiency, and may lead to non-productive operations
What?

A single point of service for a suite of measurements:

- Hookload
- Torsion
- Bending moment/angle
- Rotation speed
- Height (depth)
- Flowrate
- Mud density
- Mud pressure
- Mud temperature
- Drillstring vibrations
Primary System Features

• Reliability & quality
  • Robust communications, calibrated sensors

• Synchronicity of measurements
  • Priority for valid data correlations
  • Common sampling and data transmission clocks

• Power conservation
  • Sensor selection by rig activity
  • Maximizes run time between battery recharges
Measurement Commonalities

Each sensor:
- has a documented calibration
- has high accuracy, low power consumption
- acquires measurements at user-configured frequencies
- located in weatherproof, noble gas filled enclosure

Each measurement:
- is direct in relation to the load path
- is made simultaneously with all others
- is available on command
<table>
<thead>
<tr>
<th>Measurement</th>
<th>Sensor Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight, torque, bending moment &amp; angle</td>
<td>Strain gages</td>
</tr>
<tr>
<td>Block height</td>
<td>Laser rangefinder</td>
</tr>
<tr>
<td>Rotation speed</td>
<td>Magnetometer, rate gyro</td>
</tr>
<tr>
<td>Pressure &amp; temperature</td>
<td>Thin film strain gages</td>
</tr>
<tr>
<td>Flowrate and mud density</td>
<td>Ultrasonic</td>
</tr>
<tr>
<td>Axial, torsional, lateral vibrations</td>
<td>Strain gages</td>
</tr>
</tbody>
</table>
## Measurement Ranges

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Estimated Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension/compression</td>
<td>0 – connection yield</td>
</tr>
<tr>
<td>Torsion</td>
<td>0 – connection yield</td>
</tr>
<tr>
<td>Bending moment</td>
<td>0 – connection yield</td>
</tr>
<tr>
<td>Rotational speed</td>
<td>0 – 200 rpm</td>
</tr>
<tr>
<td>Height</td>
<td>0 – 150 ft</td>
</tr>
<tr>
<td>Pressure (mud)</td>
<td>0 – 7500 psi</td>
</tr>
<tr>
<td>Temperature (mud)</td>
<td>0 – 250 F</td>
</tr>
<tr>
<td>Mud flowrate</td>
<td>100 – 1800 gpm</td>
</tr>
<tr>
<td>Mud density</td>
<td>7.0 to 20.0 ppg</td>
</tr>
</tbody>
</table>
Primary SDM System Sensors

- Flow & Density
- Strain Sensor
- Magnetometer, Gyro, Diagnostics
- Pressure & Temperature
- Rangefinder
- Strain Sensors
Other SDM Sub Features

- Master Controller & Radios
- Battery Pack (1 of 6)
- Secondary Pressure Containment
- Pressurized, argon filled chamber
- Antennae Housing
- Recharge, comms, and power port
SDM Sub - Physical Envelope

- Connections
  - NC40, NC46, NC50, 6 5/8”, 7 5/8”
- Mandrel
  - 8.0”, 10.0” OD, with 3.0”, 3.25” ID
- Length - 22 ½” shoulder-shoulder
- Chamber OD – 13.5” – 16.0”
Hookload, Torque, Bending Moment & Angle

- Strain gage measurements from 3 pockets
  - Oriented at 120° in same horizontal plane
- Sensors are full Wheatstone bridges
- Each pocket has 1 weight & 1 torque sensor
- Values are averages of 3 sensors
- Bending moment and Bending angle
Tension, Torsion & Bending Moment Calibrations

- Honeywell load cells with NIST traceability used for load calibrations
- 124 + calibration stations for 66 scale & bias factors
- Corrections for differential pressure and temperature
Height (Depth) Sensor

• Eye-safe laser rangefinder
• Distance measured by time of flight
• No special target required
  • reflects from any surface
• Factory calibrated
  • 0.8” accuracy at 100’, or 0.07% RD
• High sampling rate
  • can provide instantaneous ROP
Pressure & Temperature Sensors

- Digital sensors
- Thin-film strain gages
- Full Wheatstone Bridge
- Factory calibrated
- Full scale 7500 psi
  - 0.025% accuracy
- Nickel RTD temperature
  - Accuracy ≈ 1.0%
Mud Flowrate Sensor

- Flowrate derived from measurement of velocity
- Velocity measured by ultrasonic transit time differences
- Upstream & downstream sensors
- Independent of pressure, temperature & fluid density
- Accuracy ≈ 0.5% of reading
Ultrasonic Flowmeter Responses to Flowloop Pump Flowate

$R^2 = 0.9985$
Mud Density Sensor

• Same sensor used for flowrate is used for mud density
• Density is derived from a speed of sound measurement together with a measure of signal attenuation
• Empirical tests are ongoing now
  • Results to date are very encouraging
    • 8.8 to 16.3 ppg WBM
  • Tests at temperature and pressure planned for summer 2016
  • Tests to 850 gpm, WBM & OBM at Houston flow loop in September
  • Accuracy is TBD
Telemetry Channels & Radios

3 data channels:

• Uplink – Instructions – 154.6 MHz

• Principal Downlink Channel – 154.6 MHz Radio
  • Data and quality indicators transmitted from sub to rig floor
  • Wrap-around antenna, no “dead” transmission spots

• Secondary / Fast downlink – 2.4 GHz Radio Frequency
  • Can be subject to multipath signal interference - Uses multiple “patch” antennas
  • Meant for possible transmission of vibration data not processed by onboard digital signal processor
Data Transmissions

- Data telemetered in packets, with redundancy checks, sequence identifications, acknowledgements

- Each sensor data packet contains a quality indicator

- Message frequency configurable, from 1 to 500 Hz

- Data rate of primary radio is 200 kbps; max. throughput is on the order of 1.4 Mb per minute
Data Sampling & Processing

• User creates “Tasking Tables”, instruction sets uplinked to sub’s Master Controller for:
  • sensors selection
  • sampling rate for each sensor (1 to \(\approx 500\) Hz for most sensors)
  • processing for each (type of averaging: mean, mode, RMS, etc)
  • number of samples to average for each (max 256)
  • sampling clock frequency (1 to 500 Hz)
  • radio (transmission) clock frequency (1 to 500 Hz)

• Custom Tasking Tables for different operations
  • e.g., drilling, short trip, well control, other user scenarios.
# Example Setup of Sensor Sampling & Update Rates

<table>
<thead>
<tr>
<th>Measurement</th>
<th>&quot;Typical&quot; Sampling Rate</th>
<th>Value Update Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block Height</td>
<td>100</td>
<td>0.1</td>
</tr>
<tr>
<td>Hookload, Torque</td>
<td>50</td>
<td>1</td>
</tr>
<tr>
<td>Rotary Speed</td>
<td>50</td>
<td>0.25</td>
</tr>
<tr>
<td>Mud Pressure</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Mud Temperature</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>Flow Rate</td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>Mud Density</td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>Vibrations</td>
<td>450</td>
<td>1</td>
</tr>
</tbody>
</table>
Rigfloor Console & Communications Module

- Rig floor Communications Module
  - Contains the antennas for the two radios
  - Contains the two radio circuits
  - Uses Power over Ethernet for comms to Rigfloor Console
- Rig floor Console (Can be integrated into Customer provided EDR system)
  - Receives all data from sub, timestamps, and passes transparently to EDR
  - Displays data for driller
  - Performs minimal processing, algorithms for basic functions (eg, connection identification, calculation of weight on bit)
  - Uploads instructions (Tasking Tables) to topdrive sub
Status of System Components: 4/1/2016

- **SDM Sub**: Mostly completed; limited tests performed; Flowrate & density sensors require more testing
- **Rig floor Comms Module**: Prototype made & tested
- **Rig floor Console**: Basic GUI—Customizable for / by user
- **Performance EDR System**: Customizable by user
THANK YOU

QUESTIONS & COMMENTS

Instrumented Top Sub