New Shock Sensing Sub Permits Greater Understanding of the Dynamic Response of Perforating Gun Strings

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Agenda

- Introduction
- Perforating System Optimization Methodology
- Shock Sensing Sub
- Field Trial 1 Job Description
- Field Trial Data
- Field Trial 2 Job Description
- Field Trial Data
- SSS for FEA Model-Data Validation
- Summary and Conclusion
Introduction

- Current well designs are pushing the limit of perforating gun design
- Traditional gun design approaches need improvement
- Loads imposed during the perforating event should be better understood to maximize charge performance and ultimate productivity
- Dynamic events in longer perforating strings need to be better understood
Methodology

- CTH simulation
- Surface testing
- Advanced flow lab
- Down hole data
- FEA analysis

Optimized system performance
Down Hole Data - Shock Sensing Sub

Developed a sub to collect data anywhere in the string
Each channel provides 100,000 data samples per second:

- Acceleration
- Mechanical strain/stress
- Dynamic wellbore pressure
- Pressure/temperature/mechanical states

Handled like a loaded gun
Shock Sensing Sub

<table>
<thead>
<tr>
<th>Mechanical</th>
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<tbody>
<tr>
<td>Diameter</td>
<td>4 5/8 in.</td>
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<tr>
<td>Pressure rating</td>
<td>20,000 psi</td>
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<tr>
<td>Tensile rating</td>
<td>377,000 lbm</td>
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<tr>
<td>Connections</td>
<td>Standard gun threads (pin x box)</td>
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<table>
<thead>
<tr>
<th>Sensors</th>
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<tbody>
<tr>
<td>Strain gages</td>
<td>3 axial, 3 hoop, 1 torsion</td>
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<tr>
<td>Pressure</td>
<td>Dynamic pressure, 100 ksi</td>
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<tr>
<td>Accelerometers</td>
<td>Triaxial, 60 kg</td>
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<tr>
<td>Temperature</td>
<td>RTD</td>
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<table>
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<tr>
<th>Environmental</th>
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<tbody>
<tr>
<td>Temperature rating</td>
<td>302ºF</td>
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<th>Logging</th>
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<tbody>
<tr>
<td>Event sampling rate</td>
<td>100 kHz</td>
</tr>
<tr>
<td>Event duration</td>
<td>1 sec</td>
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<td>Event records</td>
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<td>Run duration</td>
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Field Trial Job 1 Description

- Gun system: 4 5/8-in., 5 shots/ft using 39-g HMX charges
- Perforation depth approximately 7,500 ft
- Bottom hole temperature 215°F
- Fast Gauge™ on the bottom of the string
- Two Shock Sensing Subs one towards the top of the string and one at the bottom of the string
Validation Against Fast Gauge
Dynamic Events

- Pressure measurement:
  - Upper Sub positioned five guns from the top of string
  - Lower SSS placed at base of string
- Pressures and loads are not the same across the string
- Multiple tools can be used to record the pressure event at different locations in the string
- Placing fast gauges at the base of the string does not give a full understanding of the dynamic pressure events at different locations in the string
Dynamic Events

- Strain measurement:
  - Upper Sub positioned five guns from the top of string
  - Lower SSS placed at base of string
- The tool at the base of the string captures the initial event
- By placing tools at the base / top of the string you do not capture the loads within the gun string
Job History

Set packer

Fluid draining to formation

MDBV open

POOH

Pumping fluid

Unset packer

pumping fluid

reservoir pressure

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Field Trial Job 2 Description

- Gun system: 4 5/8-in., 12 shots/ft using 28-g HMX SH LD charges
- Perforation depth approximately 16,000 ft
- Hydrostatic pressure 12,400 psi
- Bottom hole temperature 190°F
- Fast Gauge™ recorder 40 ft below the packer
- Shock Sensing Sub placed between firing head and top gun
Down hole Data

- Selected pressure results:
  - Shock Sensing Sub
  - Fast Gauge recorder
- Shock Sensing Sub pressure measurement against accepted tool

- Internal validation of pressure results:
  - Dynamic pressure sensor
  - Strain-based estimate
- Excellent correlation between two independent measurement sources on the Shock Sensing Sub
Down hole Data

- Strain measurements:
  - Axial strain (0°, +120°, -120°)
  - Hoop strain (0°, +120°, -120°)
- Divergence of axial stresses indicates bending response
- Delayed onset of bending caused by difference in speed between dilatational and bending waves
- Hoop stress mirrors pressure
- Results can be processed to calculate average stress and ultimately, loads
Job History

- Running in hole
- Perforating event
- Tag sump packer
- Tag sump Packer

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SSS for FEA Model-Data Validation

- Used for calibration of full string model:
  - Pressure
  - Stress

- Pressure:
  - Accurate prediction of dynamic underbalance
  - Accurate capture of principal events and dynamics

- Stress:
  - Good representation of dynamic events
  - Good representation of overall stress levels
Summary and Conclusions

- The new Shock Sensing Sub is designed to record and better understand the load and pressure events during perforating jobs:
  - Direct measurement of loads within the string
  - Direct measurement of dynamic pressure at any point in the gun string
  - The ability to have a complete record of the job history including pressure, temperature, acceleration, stresses and loads

- Improved understanding of the dynamics during perforating through acquired down hole data will ultimately lead to better gun design

- Utilizing the SSS in longer string gives the opportunity to confirm dynamic underbalance models and allow optimization for future wells

- Down hole data revealed interesting gun string dynamics and reasonable match between down hole data and simulations