Vibratory Downhole Tools for Horizontal Drilling and Extended Reach Completions –
A Technology Overview

11/29/2012
Roger L. Schultz
TTS Drilling Solutions
Presentation Overview

• Frictional Forces in a Horizontal Well
• Discussion of Various Vibration Tool Types
• Review of Test Data
• Questions?
Frictional Forces

- Frictional forces caused by forced contact between coiled tubing/drillpipe and casing/wellbore.

- Forced contact caused by:
  - Buckling (sinusoidal and helical)
  - Deformed coiled tubing
  - Deviated wellbore
  - Gravity acting on pipe in horizontal section
  - Hydraulic loading against wellbore

- Friction coefficients effected by
  - Sand and debris
  - Casing/Wellbore condition
Buckling in Coiled Tubing Strings

Sinusoidal Buckling in the Horizontal Section

\[ F_{critical} = 2 \sqrt{\frac{EIW_e}{r}} \]

Helical Buckling in the Horizontal Section

\[ F_{critical} = 2(2\sqrt{2} - 1) \sqrt{\frac{EIW_e}{r}} \]

Sinusoidal Buckling in the Vertical Section

\[ F_{critical} = 2.55(EIW_e^2)^\frac{1}{3} \]

Helical Buckling in the Vertical Section

\[ F_{critical} = 5.55(EIW_e^2)^\frac{1}{3} \]
Buckling in Coiled Tubing Strings

Example: 2”, .156” wall CT, 17# 5.5’ casing, 8.8#/gal mud

\[
F = 30,000,000 \text{ psi} \quad r = \frac{(4.892” - 2”)/2}{1.44 \text{ inch}}
\]

\[
I = \frac{\pi(D_o^4 - D_i^4)}{64} = \frac{\pi(2^4 - 1.688^4)}{64} = 0.387 \text{in}^4
\]

\[
W = 3.07 \frac{\text{pounds}}{\text{foot}} = 0.256 \text{ pound/inch}
\]

\[
W_e = W \left(1 - \frac{\text{mud weight}}{\text{water weight}}\right) = 0.256 \left(1 - \frac{9.8}{65.5}\right) = 0.221 \text{ pound/inch}
\]

**Sinusoidal Buckling in the Horizontal Section**

\[
F_{\text{critical}} = 2 \sqrt{\frac{30,000,000(0.387)(0.221)}{1.44}} = 2,670 \text{ lbf}
\]

**Helical Buckling in the Horizontal Section**

\[
F_{\text{critical}} = 2(2\sqrt{2} - 1) \sqrt{\frac{30,000,000(0.387)(0.221)}{1.44}} = 4,881 \text{ lbf}
\]

**Sinusoidal Buckling in the Vertical Section**

\[
F_{\text{critical}} = 2.55(30,000,000(0.387)0.221^2)^{\frac{1}{3}} = 211 \text{ lbf}
\]

**Helical Buckling in the Vertical Section**

\[
F_{\text{critical}} = 5.55(30,000,000(0.387)0.221^2)^{\frac{1}{3}} = 459 \text{ lbf}
\]

Relatively low forces are required to buckle coiled tubing!
Why Do Vibratory Extended Reach Tools Work?

Cyclic Hydraulic Loading of CT, Drillpipe, Casing
- Oscillating back-pressure created by tool causes repeated extension and contraction of the tubing/pipe string breaking static friction.

Pulsating Flow at Bit Face
- Pulsating flow causes oscillating hydraulic loading between bit face and bottom of the borehole creating a “hammer-drill” effect.
Benefits of Vibratory Extended Reach Tools.

Coiled Tubing Applications
- Breaks static friction between CT and casing allowing BHA to reach much further out into laterals.
- Greatly reduces plug mill out times.

Drilling Applications
- 2-3+ times faster sliding ROP, 1.5-2 times faster rotary ROP
- Much better tool face control
- Less WOB required which extends bit life

Casing Applications:
- Greatly reduces force and torque required to get casing into well.
- Allows longer laterals to be cased.
- Vibrates casing and pulses cement during cementing operations enhancing cement job quality.
Types of DH Vibration/Pulse Tools

Rotary Valve Pulse Tools
- NOV (Agitator™)

Oscillatory Flow-Modulating Tools
- TTS Drilling Solutions (XRV™ tool)

Poppet/Spring-Mass Tools
- ThruTubing Solutions (Achiever™)
- Tempress™
- Others
Rotary Valve Pulse Tools

Description
This type of tool utilizes a rotor/stator pair attached to a valve element to momentarily disrupt flow to create and release backpressure above the tool.

Advantages:
- Have proven to be effective for sliding and increased ROP
- Reliable under non-extreme conditions

Disadvantages:
- High-temperature and chemical compatibility
- Tool length
- Tool failure often requires trip out of hole
- Repair cost

NOV Agitator™ (US patent 6,279,670)
Oscillatory Flow-Modulation Tool

Description
This type of tool utilizes a specialized fluid path to create a varying flow resistance which acts much like an opening and closing valve.

Advantages
- Very compact, rugged and relatively inexpensive.
- No moving parts.....highly reliable.
- No temperature limitation.
- No elastomers.....no issues with fluids or chemicals.
- Wide flowrate operating range.

TTS XRV™ (patent pending)
Poppet/Spring-Mass Tools

Description
This type of tool utilizes a combination of sliding mass/valve/spring components which oscillate in response to flow through the tool. This action creates mechanical hammering and/or flow interruption.

Advantages
- Generally simple and relatively inexpensive
- Minimal or no elastomeric components
- Short length

Disadvantages:
- Not as effective at interrupting flow
- Springs subject to high cycle fatigue
- Narrow operating range
Poppet/Spring-Mass Tools

Tempress HydroPull™ Tool (patent # 6,237,701 and 7,139,219)

ThruTubing Solutions Achiever™ Tool (patent pending)
Testing of Various Coiled Tubing Vibratory Tools

Test Configuration

Achiever™, Agitator™ or XRV™ Tool

Pressure Transducer

Data Acquisition System

High Pressure Pump
Backpressure for Various CT Vibratory Tools

NOV Agitator™
Max Pressure : ~ 1900 psi
Min Pressure : ~ 600 psi
Pulse Height : ~ 1300 psi
Base Frequency : ~ 8 Hz
Secondary Frequency : ~ 20 Hz

TTS XRV™
Max Pressure : ~ 1900 psi
Min Pressure : ~ 400 psi
Pulse Height : ~ 1500 psi
Base Frequency : ~ 28 Hz

TTS Achiever™
Max Pressure : ~ 1600 psi
Min Pressure : ~ 550 psi
Pulse Height : ~ 1050 psi
Base Frequency : ~ 12.5 Hz
Second Frequency : ~ 77 Hz
Vibratory Loading on CT

Oscillating Hydraulic Load on Tubing Due to 2.88", 3 BPM XRV Tool (@ 1, 1.5, 2, 2.5, 3 BPM)

Peak to Peak Load (pounds)

Tubing ID (inches)
4.75” XRV™ 250 GPM Rig Test

Circulating Pressure @ 250 gpm
(XRT, 1350' of Drill Pipe, MWD toolstring, Motor, Bit, 12.8 #/gal mud)

Pulse Height: 700 psi
Frequency: 11 Hz
Vibratory Drillpipe Loading

Oscillating Hydraulic Load on Drillpipe Due to XRV Tool (@ nominal flow)

![Graph showing the oscillating hydraulic load on drillpipe ID (inches) vs. peak to peak load (pounds). The load increases linearly with the increase in drillpipe ID.](image)
Casing XRV Tool

- Deployed in casing string to help get casing to bottom
  - Casing Shoe
  - Casing Collar
- Causes axial vibration of casing string as mud or other fluid is circulated.
- Creates fluid pulsation at casing shoe.
- Improves cement flow and uniformity of cement placement reducing voids and channels.
- Drillable
Vibratory Load on Casing

Oscillating Hydraulic Load on Casing Due to 4.5" XRV Tool (@ 3, 4, 5, 6 BPM)
Questions?