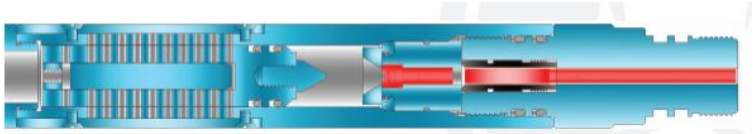
IPS-16-03

Agitating Explosives in Extended Reach Wells: A Good Idea?



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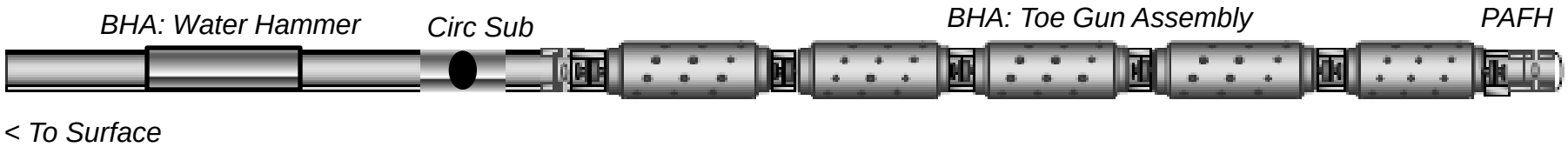
Index

- Introduction
- Operational Considerations
  - TCP system
  - Water hammer
- Current system
  - Flow loop testing
  - Testing Field trial
  - Results
  - Analysis
- Novel system
  - Performance testing
  - Flow loop testing
  - Results
  - Analysis
- Conclusion

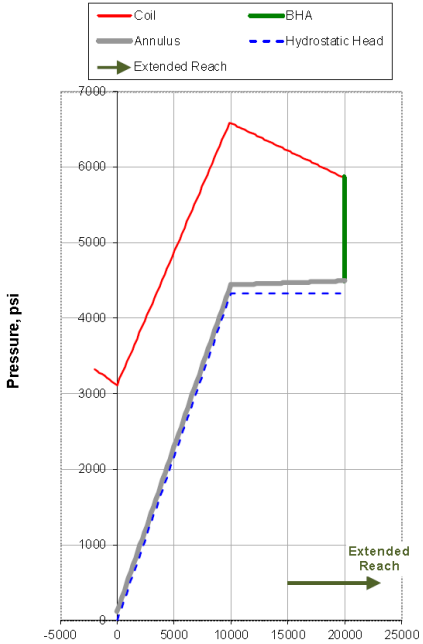
Introduction

- The total length of horizontal wells increasingly exceeds the normal running limits of coiled tubing (CT), therefore, the industry has invented and adopted the use of water hammers to emplace the coiled tubing and its related equipment into the farthest reaches of the lateral (toe).
- This equipment can include hydraulic jets, mills and motors for cleaning debris out of the well, and tubing conveyed perforating (TCP) systems (guns and firing heads) for establishing the first initial flow path into the well for fracturing and production.
- From a safety perspective, the use of TCP systems, which contain several types of discreet explosive components designed to fire based on impact (some more sensitive than others), may conflict with the use of water hammers, which axially impact the lowest components of the bottom hole assembly



Introduction

- Sometimes the industry requires this combination in extended reach wells, especially before formation breakdown where no flow path exists for pumping down wireline perforating guns, and when primary completion equipment (sliding sleeves) fails.
- Modeling tools may allow users to configure tool strings with coiled tubing, water hammers, and perforating guns, however this does not take into account the compatibility aspects regarding whether this is safe to do so.
- To truly determine the compatibility beyond simple conjecture, testing is required and has been completed.



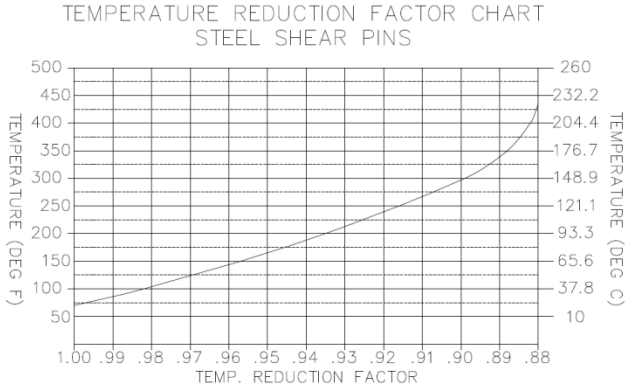
Modeling Graphic Based on Input Parameters and Results

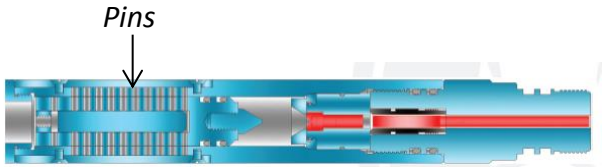
Operational Considerations

TCP Pressure Actuated Firing Head (FH)

- Actuation pressure determined by adding
  - ➢ Hydrostatic Pressure at depth of FH + Applied Pressure to achieve
    - ▪ Underbalance/ Overbalance (Based on formation pressure)
  - ➢ Minimum typically 1,500 psi above highest anticipated BHP

    + Safety factor- typically 1,000 psi
- Actuation achieved by shearing multiple steel pins
  - ➢ Each pin typically ~1000 psi @ 70° F (lot dependent)
    - ▪ Tolerance ± 5%; Affected by temperature
    - ▪ Add multiple pins to get required shear value
- Actuation process:
  - ➢ Apply surface pressure against piston held by pins
  - ➢ When pressure is exceeded, pins fail allowing firing pin to impact explosive initiator and guns fire.





Pressure Activated Firing Head

Operational Considerations

Water hammer

- Purpose
  - ➢ Extends coiled tubing (CT) operational limits
    - ▪ friction leads to loss of weight and helical buckling.
  - ➢ Water hammer pulls on the end of the CT and creates axial vibrations> delivers ~1000 psi force at bottom
    - ▪ Delivers accelerations equal to ~ 40 g
    - ▪ Allows CT to overcome friction and keep moving
- Operates based on flow through coiled tubing (~3 bmp)
  - ➢ generates increased pressure in the wellbore due to friction (100 psi)
  - ➢ generates cyclic pressure variations due to water hammer effect (184 psi)
    - ▪ not accounted for in TCP firing head calculation
      - ❖ **What effect on TCP guns- charge liners, shear pins, etc.?**

Well Designation & Date	TCP Gun	mm-dd-yy	
Well Data	US Units		
Total Vertical Depth (TVD)	10,000	ft	
Measured Depth (MD)	20,000	ft	
ID of Casing	4.67	in	
Horizontal ID (cased or open hole)	4.67	in	
Work String Data			
Length of Tubing	22,000	ft	
Tubing OD	2.00	in	
Tubing Wall Thickness	0.109	in	
BHA Data			
Minimum Flow ID in Motorhead	0.700	in	
HydroPull® Tool Diameter	2.88	inch	73.2 mm
High, Medium or Standard Impact HydroPull®	High		
Motor or Nozzle Specification	Low-Flow Nozzle		
Operating Parameters			
Fluid Pump Flow Rate	2.80	bpm	
Wellhead Circulating Pressure	100.0	psi	gage
Friction Reducer Effect	50%	% reduction	
Brine Concentration	0%	wt%	
Estimated Fluid Lost to Formation	0%	wt%	
Circulation Model Results			
Average Total BHA Pressure Drop	1375	psi	differential
Pump pressure	3348	psi	
Bottomhole Circulating Pressure (BHCP)	4491	psi	
Vertical cuttings transport ratio (1-mm sand)	72%		OK
Max Fluid Velocity Horizontal	278	fpm	OK
Water Hammer Pulse in Annulus	184	psi	differential
Minimum Rupture Disk Rating	3544	psi	
Water Hammer Pull Force	1541	lbf	
Coil Lockup MD without HydroPull™ Tool	15066	ft	
Maximum coil feed rate in toe of well	23	ft/min	
Maximum extended reach MD	23113	ft	

Modeling Input Parameters and Results

Testing- #1 Flow Loop

TCP System below water hammer:

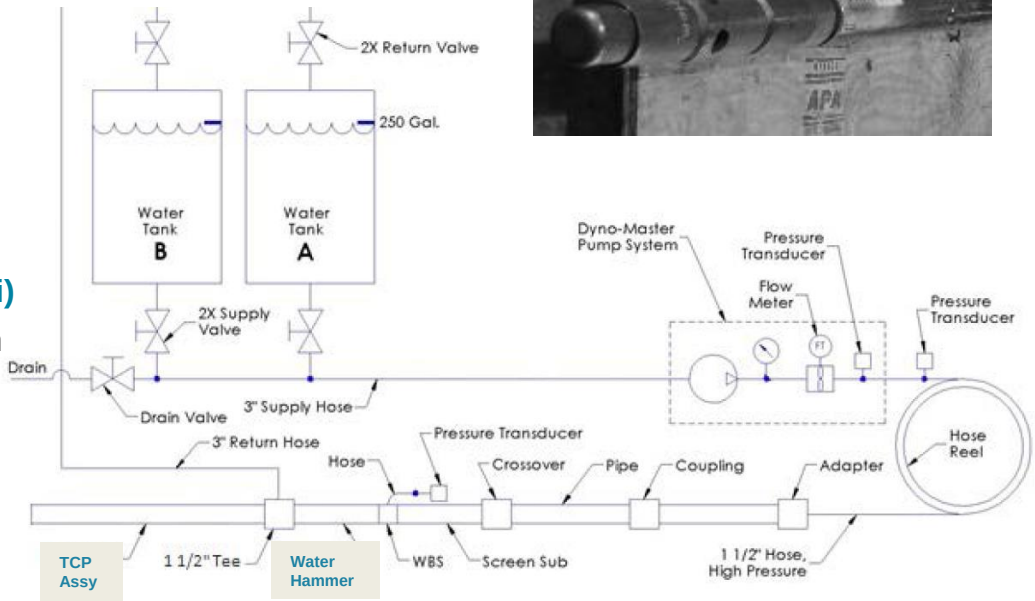
Scope:

- Pressure pulses in closed system well understood and accounted for in model-
  - So testing not required
- Accelerations and fatigue effects from long term cycling not understood for TCP equipment-
  - So focus of test

Configuration (from bottom up):

- Accelerometer mounted on firing head
- Pressure-activated firing head with **1 pin (1075 psi)**
- Quantity (4) 3-1/8” OD guns with CT subs between
  - no live explosives
  - dummy charges included (borax powder)
- 2-7/8” Water Hammer
- 2-7/8” Water Hammer Screen
- 2-1/2” pipe

Flow Loop with TCP System

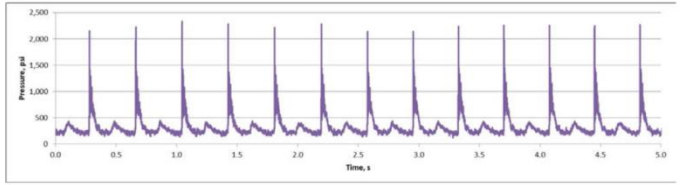


TCP firing head and gun assembly

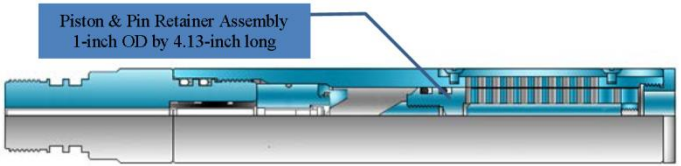
Testing- #1 Flow Loop

TCP System below water hammer:

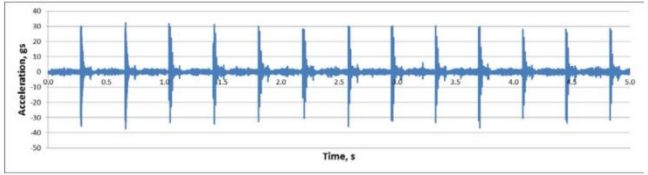
Results (after 10.75 hours= 100,000 cycles)

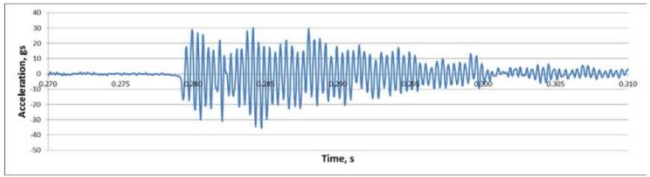


~2200 psi



- Pressure above Water Hammer @ 2.6 bpm





- Accelerations at PAFH: +30g/ -32g

- Calculations:
  - Force= Mass x Acceleration

    where peak accelerations= 40 g (±392 /m/s^2)

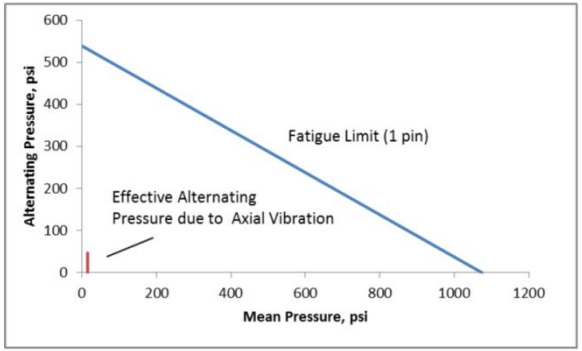
    and 1” OD piston has mass=0.42 kg,
  - So axial acceleration force= 46 psi,

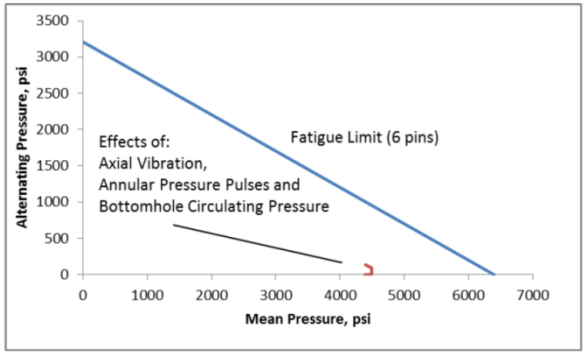
    a small fraction of the fatigue limit of 1 pin (1075 psi)

Testing- #1 Flow Loop

TCP System below water hammer:

Results (after 10.75 hours= 100,000 cycles)

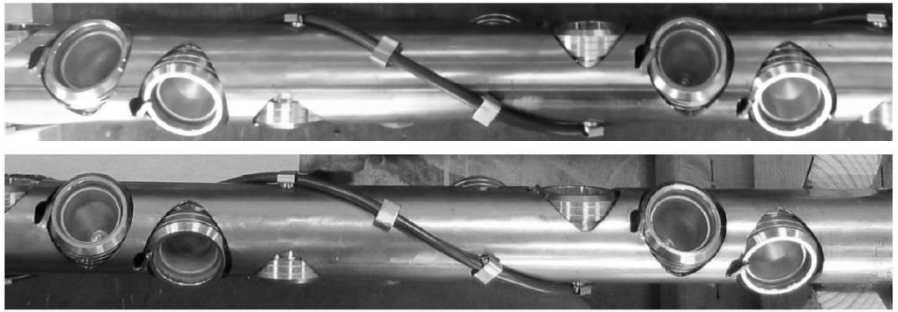




- Goodman fatigue limit diagram for a PAFH with 6 pins and BHCP with 2” CT in 5.5” casing

- Visual Inspection:
  - ➢ No damage was visible:
    - No loosening of liners
    - No loosening of charges in strip
    - No loosening of cord from charges

- Testing of pin afterwards fell w/in specification



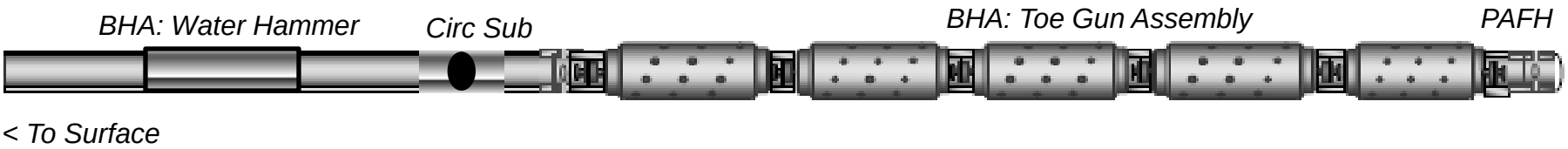
Before

After

Testing- #2 Field Trial

TCP System below water hammer:

- Well bore:
  - VD of 6600-ft
  - MD of 15000-ft.
- Initially tried to TCP w/ a 2” coil unit and could not get all the way down.
- Spent almost 2 days fighting friction.
- Client decided to get a 2-3/8” unit and run Water Hammer to try again.
- Firing Head Calculations:
  - Loaded with 6 pins
  - Nom. Actuating Pressure= 6036 psi
  - Surface Applied Pressure= **3148** psi

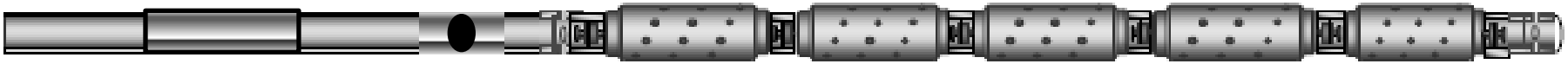


Testing- #2 Field Trial

TCP System below water hammer:

Job Record:

1. Pickup TCP
2. NU and RIH with Water Hammer/ Gun BHA
3. RIH and Rolling Pumps- ½ bpm
4. @6600-ft, up to 1.5 bpm
   @ 800-1100 psi circ pressure
5. @8900-ft, up to 2.5 bpm
   @1500-1800 psi circ pressure
6. @10,200-ft, up to 3.5 bpm
   @2300-2650 psi circ pressure
7. Slowed rate to 3.25 bpm
   @2100-2400 psi circ pressure
8. @14,989, can't go any further.
9. Take up slack, prepare to shoot.
10. Shut in well and pressure up.
11. Toe gun fired at **3120** psi>
    - good indication. Moved
12. Delay 1 fired s at 5.54 min>
    - good indication. Moved
13. Delay 2 fired at ?>
    - no indication. Moved @ 6.5 min
14. Delay 3 fired at ???>
    - no indication. Moved at 6.5 min
15. Delay 4 fired at 5.03 min>
    - good indication
16. Waited 10 min, POOH
17. OOH with BHA> all shots fired

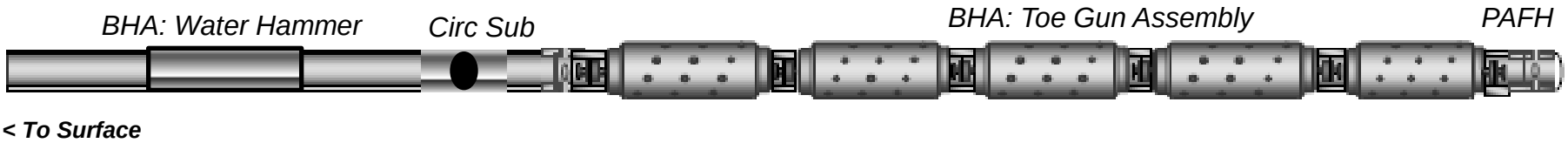


Analysis/ Results

Analysis of Current system:

- Requires two separate runs for clean-out and TCP
- Water Hammer with circulation ports must be run above TCP assembly
- This leaves 30-40 feet of guns being bullheaded in with no flow support (not effective for cleaning).
- Better option would be to move the Water Hammer/ Circulating Port/ Clean-out tools below

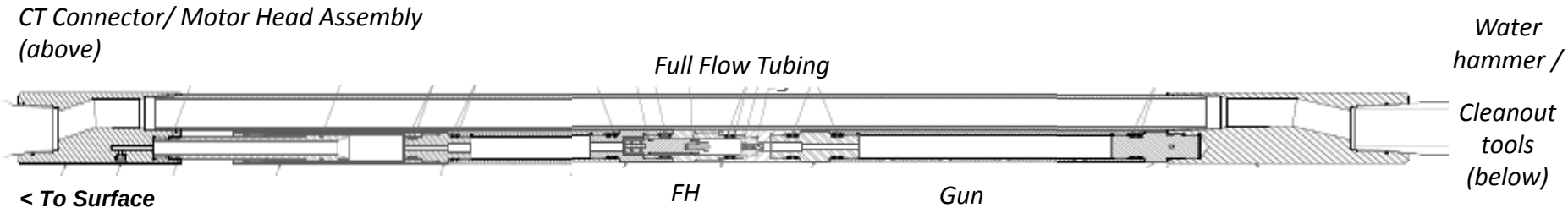
As Tested:



Novel Approach

One-trip system (part of which is patented- Henke (2010), US Patent #7650947):

- One-trip design eliminates 1 coiled tubing run- combines water hammer/ clean-out/ TCP
- Full flow tubing (1.50 ID) parallel to guns optimizes performance of water hammer/ clean- out tools
- Annular pressure activated firing head- rupture disk + pins for dual safety
- Low-side BH gun to optimize EHD for establishing flow



Testing- #3 Gun Performance

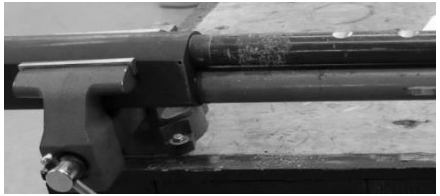
TCP System above water hammer:

Scope:

- Ensure that the gun system produced adequate perforation flow area to break down formation
- Ensure that the parallel flow tube was not damaged from perforating operation
    - Visual inspection after perforation test

Configuration:

- Fully loaded gun- 4-ft x 1-9/16 4 SPF @ 0° Phase
- Quantity (12) 3 gram HMX BH charges
- Loaded assembly was placed in 4-1/2” HW Casing (12.1 ppf)
- Gun and casing were placed horizontally in a remote water pit
- Electrically detonated due to surface test limitation



View of One-Trip System

Gun Avg EHD= 0.21 in.

Casing Avg EHD= 0.35 in.

Testing- #4 Flow Loop

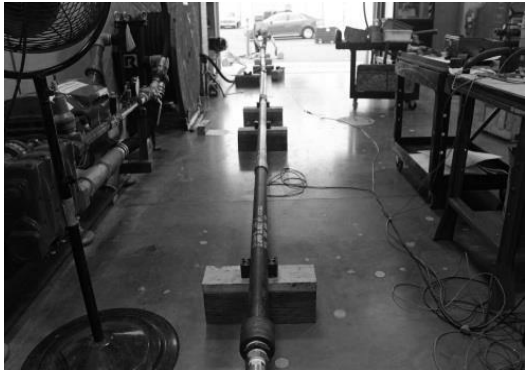
Novel TCP System above water hammer:

Scope:

- Accelerations and fatigue effect from long term cycling- not understood for TCP assembly
- Ensure that the parallel flow tube was not damaged from perforating operation
  - Flow test through tubing to confirm no damage occurred.

Configuration (from bottom up):

- Mill & Motor (simulated- reservoir with mass followed by orifice)
- 2-3/8” Water Hammer
- Transducer Sub
- Screen assembly (keeps solids/ debris out of Water Hammer).
- TCP Assembly- PAFH had **1 pin (1075 psi)**
- Transducer
- Lubricator (replaced with Coiled Tubing Motor Head assembly in live well BHA)
- Pump rate ~ 3 bpm (maximum for system)



View of Flow Test (from bottom up)

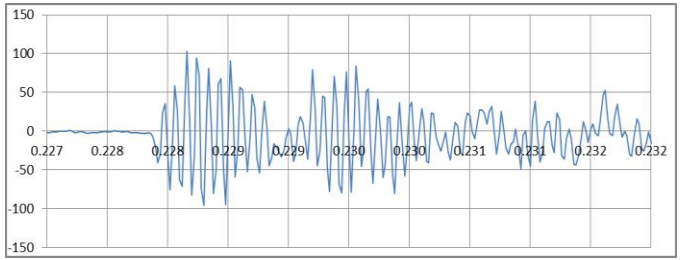
Testing- #4 Flow Loop

Novel TCP System above water hammer:

Results (after 100,000 cycles)

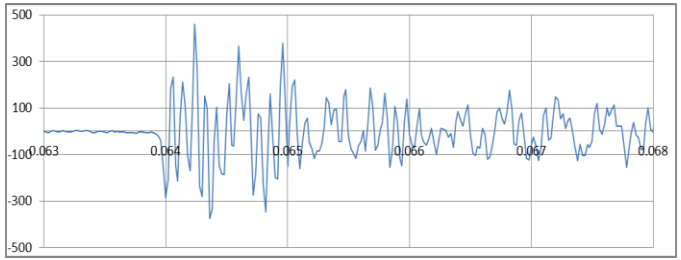
- Pressure at pump measures 640 psi average, however Water Hammer pressure pulses far exceed that (high amplitude but short duration).

  Note: Pressure pulses should not cause premature actuation of rupture disk since pulses are internal to tool and rupture disk is annular.



Accelerations above TCP Assy

- Measured Accelerations "+" = downhole, "-" = up hole
  - above Water Hammer: +670g/-610g over allmax, +540g/-490g ~avg.
  - above One-Trip: +133g/-127g overall max, +/-100g ~avg.
  - @ Firing Head: +465g/-405g overall max., +370g/-320 ~avg.
    - ~10x higher than previously measured with Water Hammer above TCP assembly

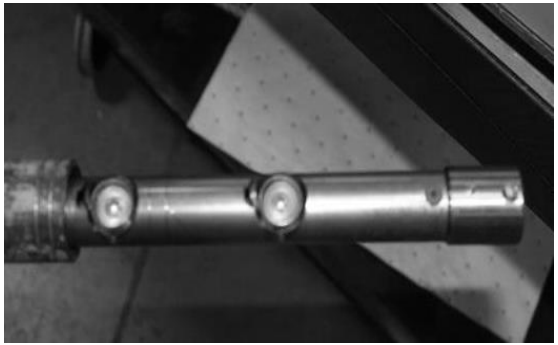


Accelerations at Firing Pin

Testing- #4 Flow Loop

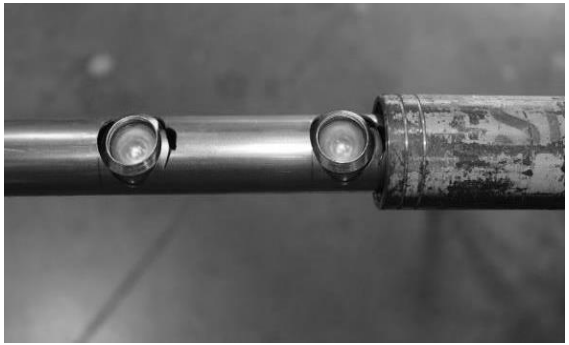
Novel TCP System above water hammer:

Results (after 100,000 cycles)



Before: Charges in strip

After: Firing & Shear Pins- No Damage



After: Charge liners and Position- No Damage

- Visual Inspection:
  - ➢ No damage was visible
    - ▪ No loosening of liners
    - ▪ No loosening of charges in strip
    - ▪ No loosening of cord from charges
    - ▪ Testing of pin afterwards fell w/in specification

Analysis

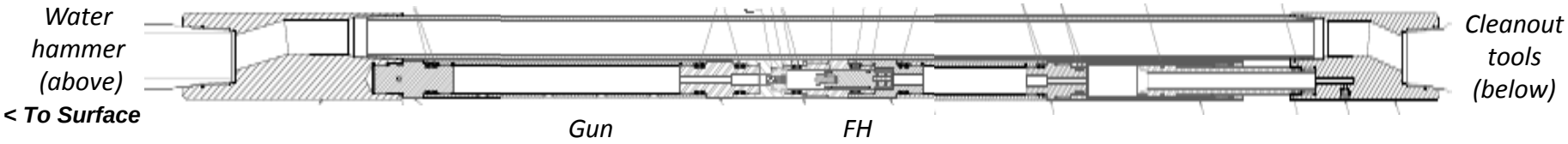
Novel TCP System above water hammer:

Conclusion:

- Accelerations were 10x higher when the water hammer was run below the one-trip TCP system.
- Calculated stress of the PAFH shear pin would be equivalent to 460 psi (based on 46 psi x 10).
- A six-pin PAFH should easily withstand this, however the safety factors are smaller.

Analysis:

- The higher level of acceleration is related to the higher flow rate and pressure spikes in the small flow tube of the one-trip TCP system.
- Recommend modifying the configuration:
  - ➢ Position the water hammer above the TCP array to reduce the acceleration levels, bending moments and pressure variation in the flow tube and connections.
  - ➢ Position the PAFH at the lower end of the TCP array- possible with no detrimental affects.



Analysis

Novel TCP System above water hammer:

Modified Configuration

Water hammer (above)

Cleanout tools (below)

< To Surface

Gun

FH

Specifications:

Casing OD (in)	Tool Only Length (in)	Flow Tube ID (in)	Gun OD (in)/ Phase/ SPF	Max. Pressure Rating (psi)	Max. Temp Rating (°F)	Gun (BH) Avg. EHD (in) API 19B	Gun (BH) Avg. Pen. (in) API 19B
4.50	119.4	1.50	1.56- 0° 4 SPF	20,000	350 f/ HMX	0.42	3.23

Note: Low-side Gun can also be run in 5" or 5-1/2" casing by using decentralizers.

- Now awaiting suitable candidate well

Conclusion

- Water hammers have proven themselves a viable option for extending reach of Coiled Tubing
- The related acceleration and pressure pulses from the downhole operation of water hammers could detrimentally affect TCP explosive components, so extensive testing has been performed.
- Flow loop testing proved that the use of water hammers when run above a typical TCP toe prep assembly can be done safely.
- A field trial validated the flow loop testing and proved that the use of water hammers when run above a typical TCP toe prep assembly can be done safely.
- Limitations:
    - Only one brand of water hammer was tested. Other types may operate differently generating different forces, so should be tested independently.
    - Operationally, current system requires two separate runs for clean-out and TCP toe prep.

Conclusion

- As a result, a novel, patented one-trip design has been evaluated which allows combining TCP equipment, water hammers and clean-out tools.
- Performance testing proved that the one-trip TCP assembly performs adequately.
- Flow loop testing proved that the use of water hammers and clean-out tools when run below the one-trip TCP assembly can be done safely.
- Benefits:
    - Clean-out tools are moved to the bottom of assembly, optimizing bottom's up clean-out
    - Full flow parallel to TCP allows high flow rate (BPM) for water hammer/ clean-out tool function
    - TCP/ water hammer/ clean-out tools all operational in one-trip system, saving one CT run.
- A field trial of the one-trip system is pending.

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Acknowledgements / Thank You / Questions

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