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2016 INTERNATIONAL PERFORATING SYMPOSIUM GALVESTON

Ultra-High Pressure Perforating System Development

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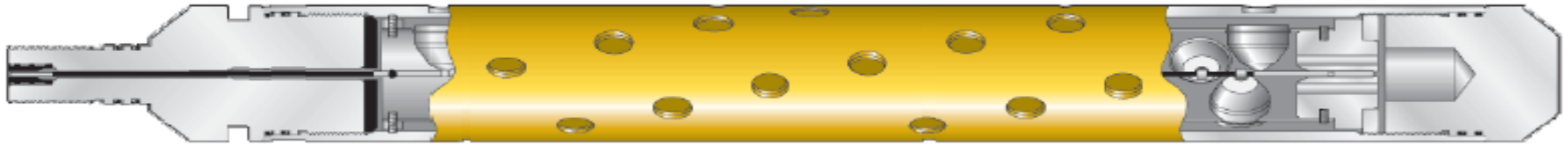
Introduction

Perforating is a critical step in establishing connectivity between subsurface zones and the wellbore in a well where the casing is cemented across the proposed production zone.

Over the past few years the need to drill wells with increasingly higher pressures and temperatures has increased and will continue to grow.

- Steel strip to hold shaped charges in place
- Shaped charges
  - Case
  - Liner
  - Main charge load
  - Primer load
- Detonating cord that connects to the back of each shaped charge
- Boosters crimped to each end of the detonating cord
- Hollow carrier into which the assembly fits
- Connecting sub (tandem)



Perforating System Requirements

What did we want to deliver in the 35,000 psi TCP system?

- A system that would withstand Ultra HPHT firing pressures.
- Limited post detonation gun swell.
- Limited wall thickness.
- Fully redundant firing system.
- Ultra deep penetrating (Hard Rock shaped charge).
- Conveyance flexibility.
- Reliability.
- High level of service quality.
- Risk reduction through up-front modeling

Steel

During the past few years, technology has greatly improved the capabilities of “high-strength, low-alloy steel”

Critical elements of both steel selection and deliver.

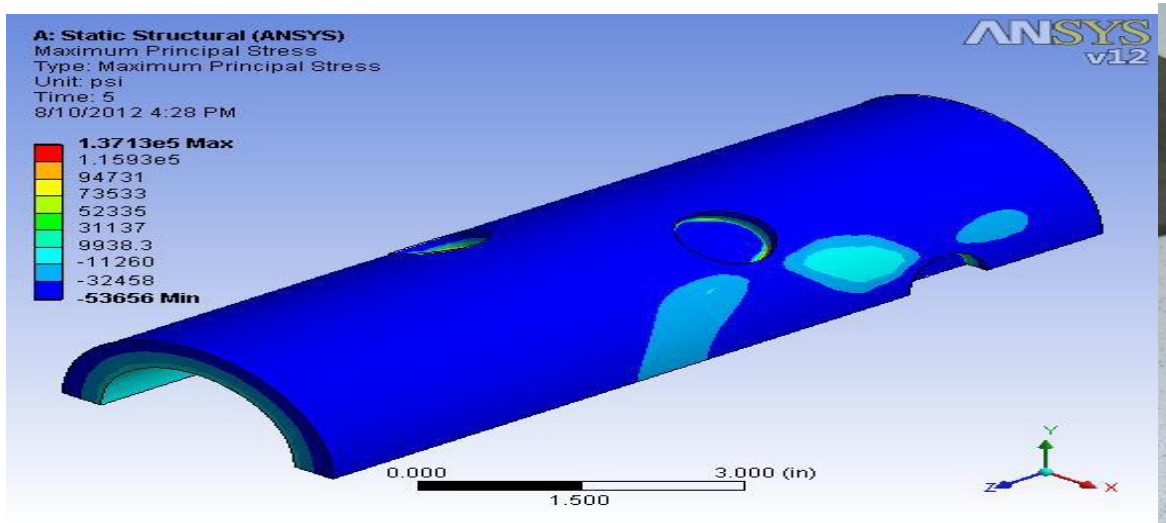
- Focus on more than yield strength.
- Work with several testing providers.
- Incorporate a test program in to the quality plan
- Work closely with all vendors.

Any detected anomaly in the material specification must be identified as early in the process as possible so that corrective action can be implemented and another run of the material can be produced.

Gun System

The gun system had to meet the following criteria:

- Include the conventional tandem sub connector.
- Pass all specification tests before and after machining.
- Post detonation survivability.
- Capable of housing a fit for purpose shaped charge.
- Maintain a safety factor.



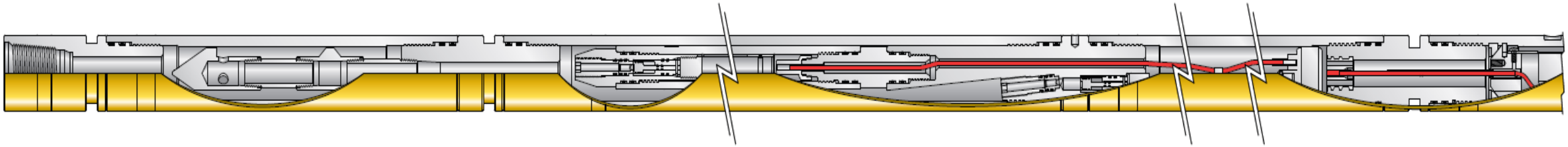
The applied pressure with the maximum principal stress of 137,130 psi at 470°F

Gun body after ballistic survival shot test

Firing System

Firing system requirements:

- Not mechanical.
- Fully redundant.
- Rupture disc activated.
- Incorporate a time delay.
- Reliable.
- Simplistic in function.
- Surface Safe.
- Tested in accordance with API RP-67.



Ultra HPHT Firing System

Explosives

The high-temperature requirement for the system meant that hexanitrostilbene (HNS) was the choice for explosive.

Due to the high-temperature requirements of the job all the explosives, including shaped charges, detonation cord, boosters, time-delay units and the ballistic transfer device were all batch qualified for use at 470° F.

Specific explosives testing included Ampule testing:

To some extent, the ampule test is the thermal stability test that most closely mimics the conditions that explosives are exposed to in oil-field operations.

Ampules containing HE sample 1 & 2

Individual Component Testing and Certification

During the development and the pre-job preparation of this project, the company worked with many third-party vendors to carry out a full range of individual component tests. These tests were based on initial findings from up-front modeling. In addition, the company had many of these tests witnessed for verification purposes.

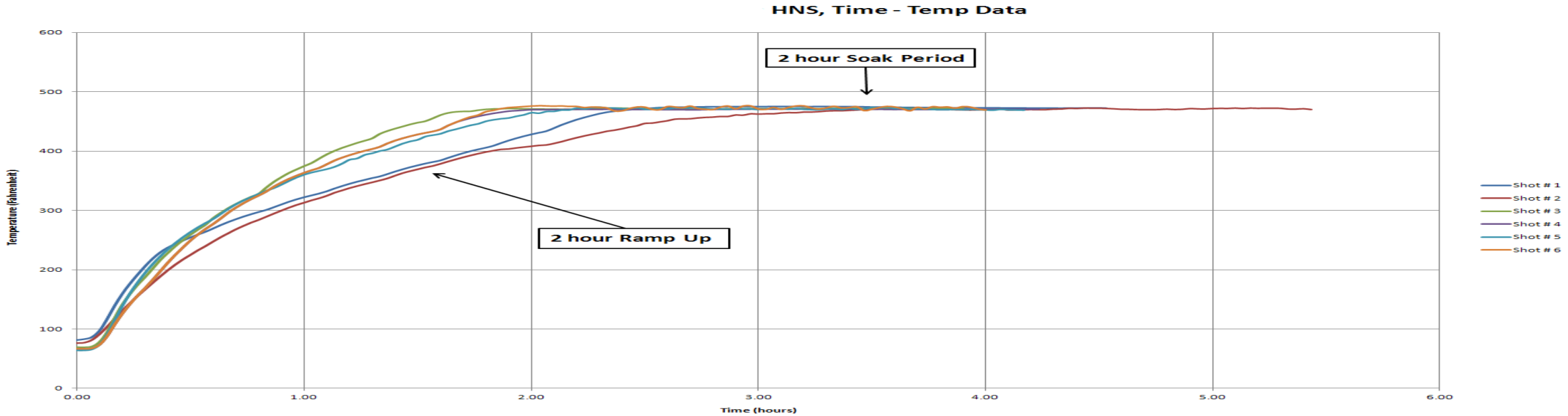
- Tandem sub connectors
- Firing head components
- Gun system & components

Many items were included in the design verification phase of the project with everything else being certified through the quality plan.

System Qualification

Many tests were completed during the system qualification phase of the project:

- Gun system first article of machined gun bodies. (both pressure and temperature)
- Ballistic survivability tests done on qualified gun bodies.
- Post detonation gun drift test. (3.625”)
- Shaped charges test fired after temperature soak.
- Explosives time delay and transfer blocks functioned after temperature soak.
- Detonating cord and booster test fired after temperature soak to ensure ballistic transfer.



Time-Temperature graph for explosives testing

System integrity Test, SIT

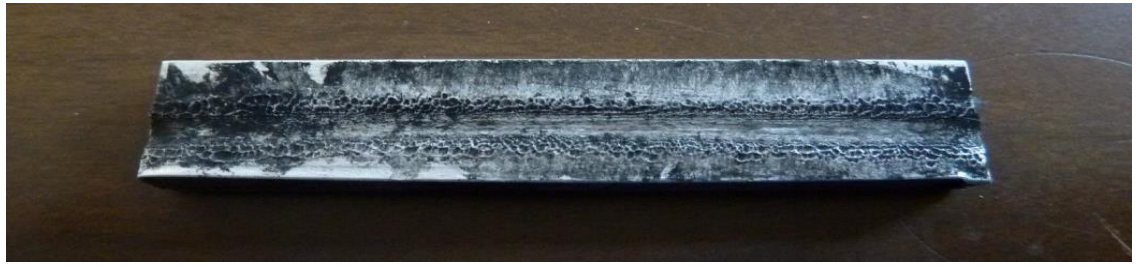
This was the final test performed to qualify the system for use as per the customer specified well conditions.

All items used in the test were from the same batches that were previously qualified for use in the well.

A 34,500-psi rupture disc was used in the firing heads. The entire assembly was lowered into the pressure vessel, and the vessel was then sealed. Temperature and pressure were then increased in a linear ramp from 72° F to 470° F (Approx. 11F every hour) and 0 to 28,000 psi, respectively over a period of 38 hours as this would mimic the temperature and pressure increase of running in hole.

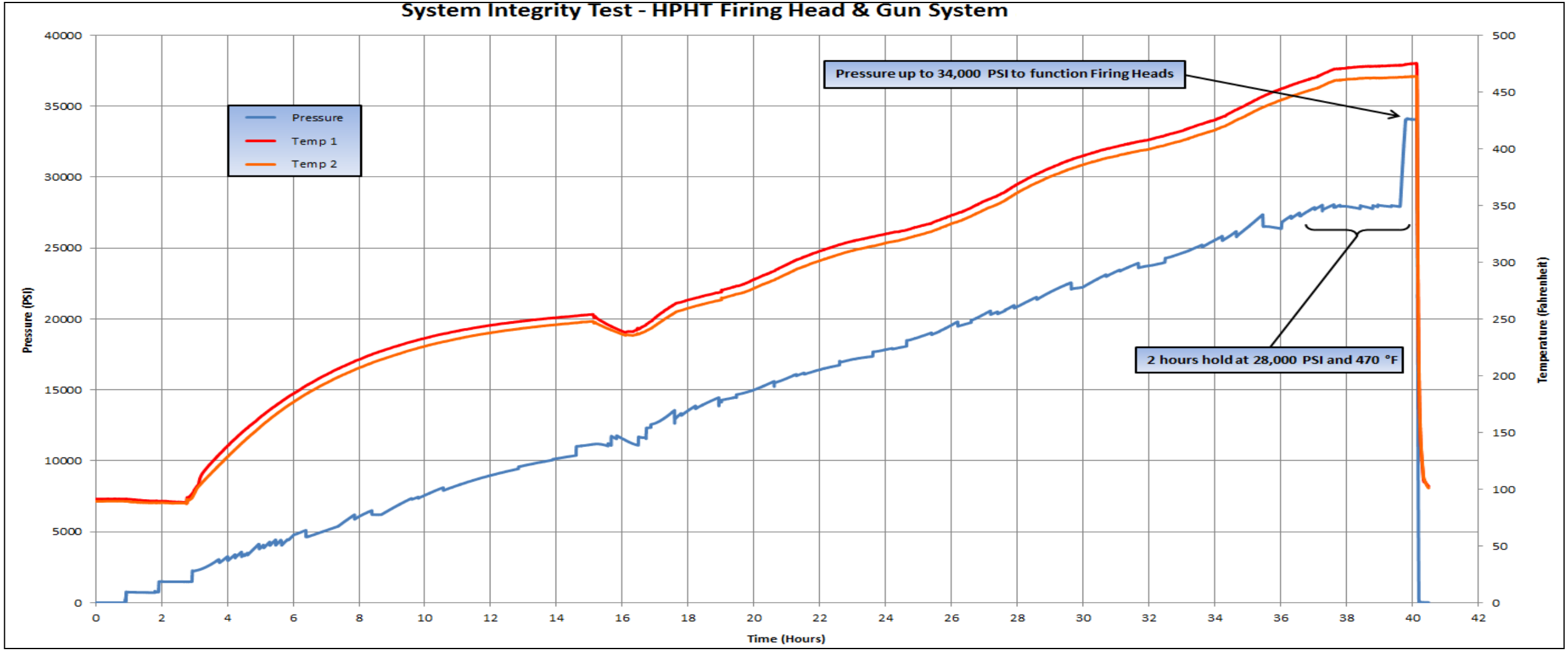
- 2 x Guns with witness plate to confirm high order detonation and transfer
- Redundant firing head system
- 34,500psi rupture discs

The system was then function at 34,000psi, with a good indication of detonation after 4 minutes 28 seconds.



Witness plate from test above, showing high-order detonation of the detonating cord

System integrity Test, SIT



Time – Temperature data for the duration of the test

Quality Plan

Other than the testing that was conducted on the component parts and the complete system integrity test, the quality plan is one of the fundamental elements that made this project delivery possible.

The quality plan was written by the company's quality assurance manager, who was fully integrated with the ballistics engineering group and who also had direct line of sight to the TCP product line team, enabling all parties to work together to streamline the process.

Hardware:

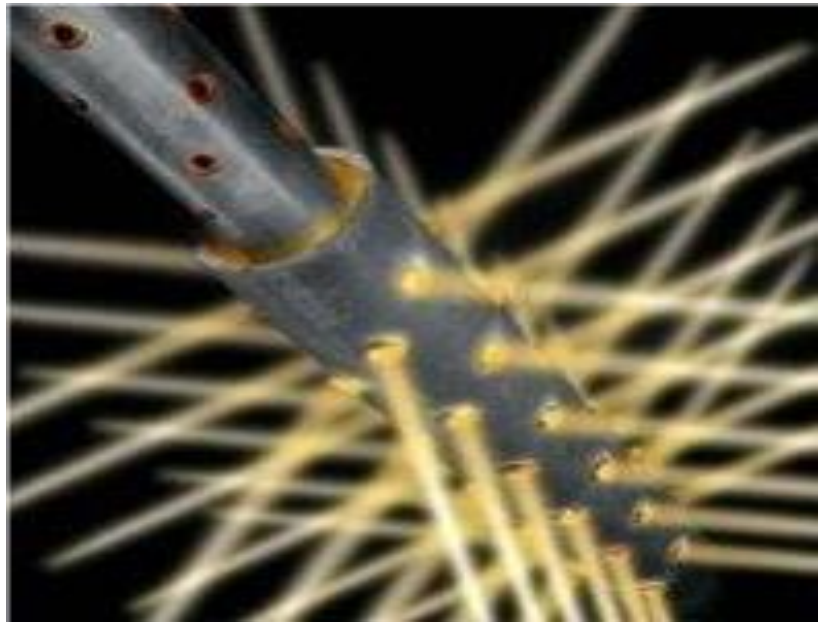
- Pressure qualification of finished gun lot
- 100% hardness testing
- 100% seal bore surface finish inspection
- 20% ultrasound gun scallop thickness
- 100% scallop and phasing dimensional inspection
- 100% OD, length, ID drift, thread, seal bore

Third-party Components:

- Velocity testing of detonating cord
- Booster transfer tests
- Manufacture date less than two years
- Time delay transfer test lot
- Transfer block tests lot
- X-ray time delays lot
- X-ray detonating cord
- X-ray boosters

Shaped Charges:

- QC production lot acceptance testing
- Increased inspection rate
- Built to order
- Booster sensitivity to test shots (Gap test between detonating cord and shaped charge)



System Deployment

- Deployed in the Gulf of Mexico
- Fired with an absolute pressure of 34,500psi @ 470F
- The system was deployed with “rock optimized shaped charges”
- Detailed static & dynamic event modeling conducted
- Full transparency with the customer
- 100% successful deployment with no HSE incidents
- Guns recovered and full high order confirmed

Conclusion

In conclusion it is without question a challenge for any organization to develop a technology that is required for such extreme conditions. However, with the correct team in place, combined with a full understanding of the requirements these products can be delivered successfully on time for any project.

- Work closely with all parties from the start of the project.
- Use more than one independent test facility.
- Be in control, do not accept any additional risk for a project.
- As a customer be involved from the start, its your well! Make sure everything works.

Acknowledgements / Thank You

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QUESTIONS? THANK YOU!