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INTERNATIONAL PERFORATING FORUM

2016 INTERNATIONAL PERFORATING SYMPOSIUM GALVESTON

STATISTICS BASED SYSTEM DESIGN FOR PERFORATED CLUSTERS

IPS 16-08

GEODynamics®

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AGENDA

- Uncertainty in Perforation Cluster Performance
- Components of Uncertainty
  - Perforation Geometry
  - Hole Size
  - Perforation Effectiveness
  - Stage Contribution
- Statistics Based Gun Design
- Statistics Based Charge Design
- Systems for Repeatability

PERFORATING A FRACTURE CLUSTER IS AN INHERENTLY UNCERTAIN ACTIVITY

- What do my downhole perforations look like?
- Do I have the right number of clusters?
- Do I have the right number of charges in each cluster?
- Will one more charge per cluster help or hurt?
- How does this cluster design interact with the formation?
- Do I have the right charge?
- Why doesn't anything I try seem to make a difference?
- What measures do I use to determine improvement?
- How does this all affect well treatment?
- Does event free treatment always mean better performing wells?

Perforation Strategies are Evaluated for Improvement with PARAMETRIC DESIGN

PARAMETRIC DESIGN

Parametric design means changing one thing at a time and evaluating the result.

- Parameters may be varied on a cluster by cluster, a stage by stage, or a well by well basis.
- The Keys to Parametric Design:
  - Keep the fixed variables fixed!
  - Change only the desired variables!
  - Understand changes that are not avoidable.
  - Evaluate the result and determine causality (or not!)

Weakness: If too many things change, results appear to be random, and one may conclude is that the change had no effect.

PERFORATION DESIGN PARAMETERS

- Tunnel Geometry (Penetration, Diameter, and Open Length)
- Hole Size in the Casing
- Hole Placement
- Number of Holes per Cluster
- Number of Clusters per Stage
- Perforation Phasing
- Perforation Shot Density

PERFORATION SYSTEM DESIGN FOR CLUSTERS

A Typical Example

- 42” penetration
- 0.40” hole diameter
- 30 Perforations/Stage
  - 5 Clusters/Stage
  - 6 Perforations/Cluster
  - 6 Shots/foot
  - 60 degree phasing
- 40 stages/well

Parameters

- Geometry
- Hole Size
- Effective Perforations/Stage
  - Effective Clusters/Stage
  - Effective Perforations/Cluster
- Stage Contribution

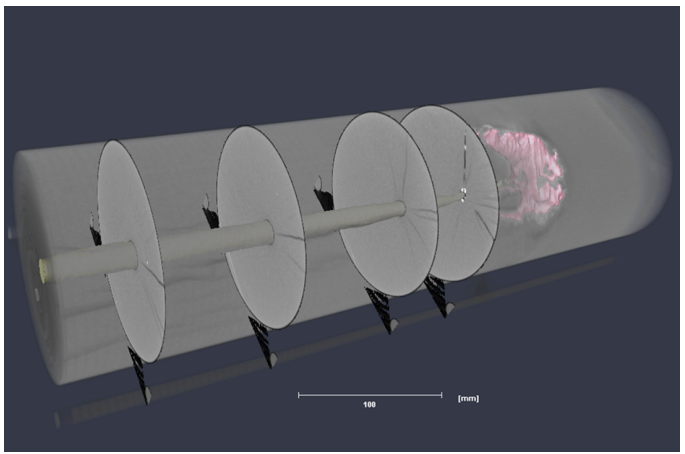
PARAMETER 1: GEOMETRY

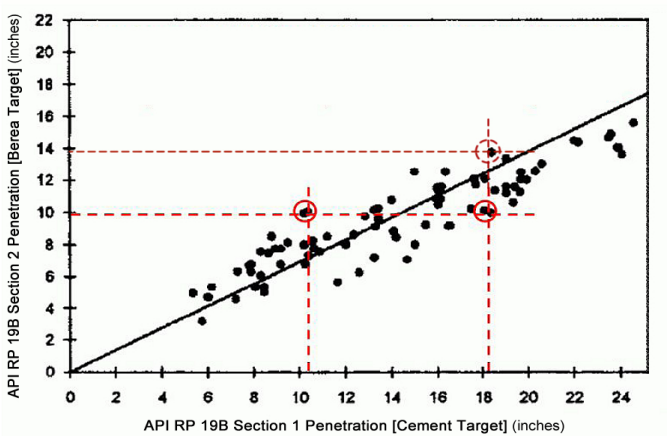
- No single perforation in a typical unconventional well has a 42” penetration

  - **SPE 124783** “Predicting Depth of Penetration of Downhole Perforators”, Gladkikh et al, Baker
  - **SPE 125020** “A Survey of Industry Models for Perforator Performance: Suggestions for Improvement”, Behrmann et al, Schlumberger
  - **SPE 127920** “New Predictive Model of Penetration Depth for Oilwell-Perforating Shaped Charges”, Harvey et al, Schlumberger
  - **SPE 149453** “Perforation Shaped Charge Design for Shale Produces Improved Tunnel Geometry”, Hardesty et al, GEODynamics

GEOMETRY: ALL 42” CHARGES ARE DIFFERENT

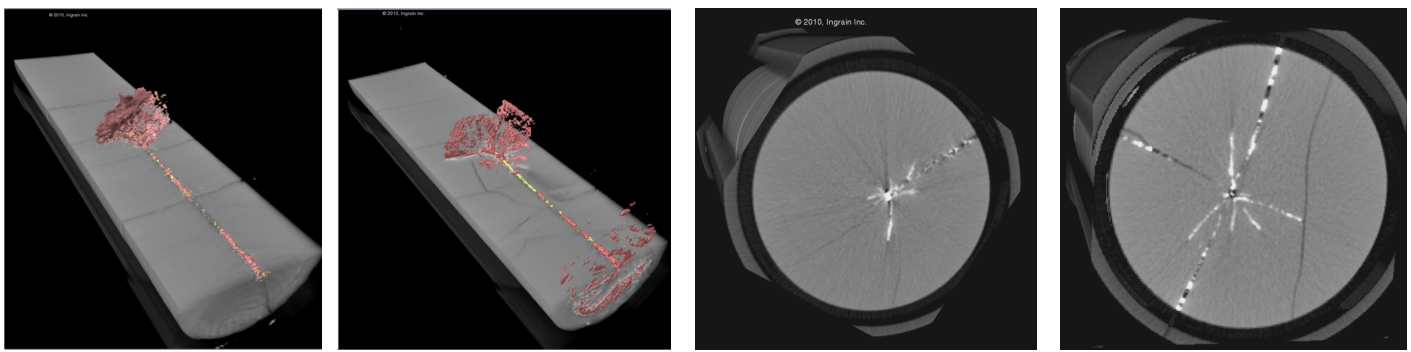
Cement Penetration does not correlate based on strength ratios
More penetration in cement does not equal more penetration in shale, or any other target.





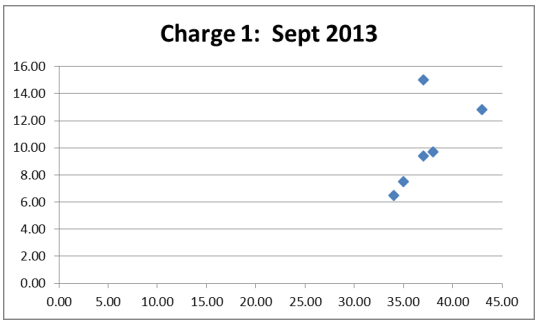
GEOMETRY: THE SHAPE IN SHALE

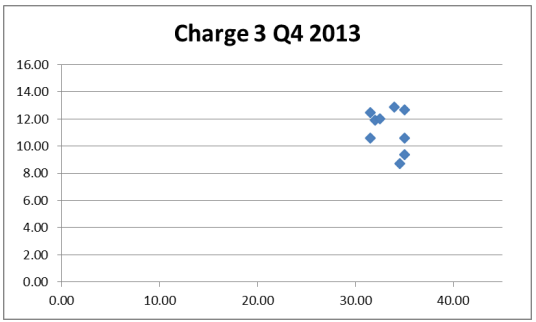
- 7 to 12 inches Total Penetration
- 3 to 9 inches Open Tunnel
- Based on charge design only – pressure condition does not affect result
- Porosity plays a strong role in penetration length

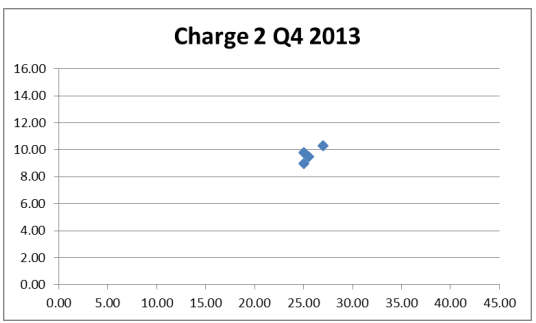


SPE149453 Perforation Shaped Charge Design for Shale Produces Improved Tunnel Geometry

GEOMETRY: TUNNEL LENGTH VARIATION



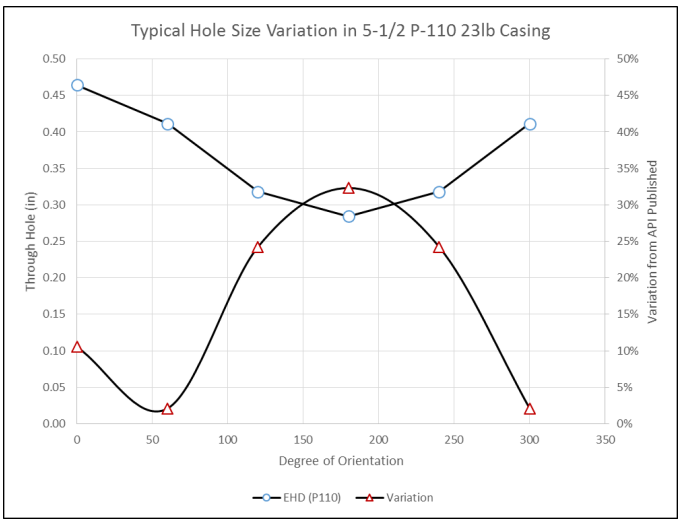




Even with acceptable cement penetration in QC targets, rock performance can vary by up to

60%

PARAMETER 2: HOLE SIZE



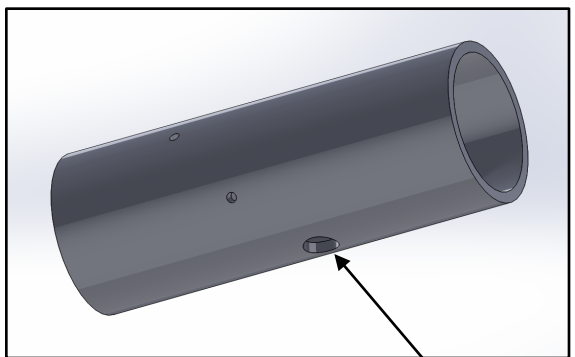
Shot No.	1	2	3	4	5	6
Phase	0	60	120	180	240	300
Clearance	0.00	0.26	0.90	1.30	0.90	0.26
API EHD	0.42	0.42	0.42	0.42	0.42	0.42
EHD (P110	**0.46**	**0.41**	**0.32**	**0.28**	**0.32**	**0.41**
Variation	11%	2%	24%	32%	24%	2%

Conventional charge designs may have hole size variation of

40%

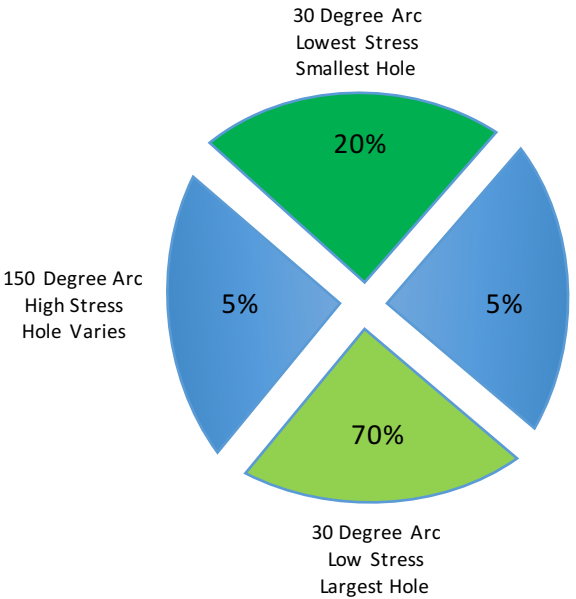
between the high and low side of the casing. Pressure drop varies with diameter to the fourth power.

PARAMETER 3: EFFECTIVE HOLES



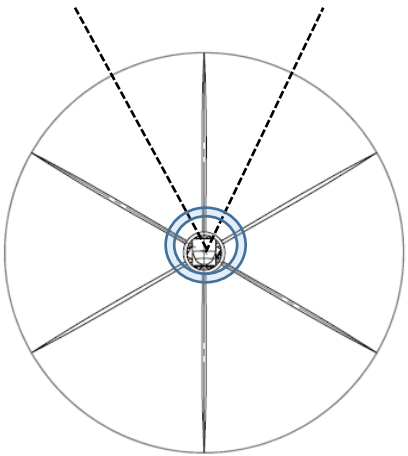
- Operators Report: Downhole cameras have shown a single dominant hole in many clusters
- The dominant hole is obvious due to preferential erosion of that hole vs. the remaining holes.
- The eroded hole is often more 2-3 times the original diameter

EFFECTIVE HOLES: WELLBORE STRESS DISTRIBUTION



- The dominant holes are approximately distributed statistically:
  - Downward 30 deg arc: 70%
  - Upward 30 deg arc: 20%
  - Either remaining side: 10%
- Conceptually, this can be accounted for due to stress distribution around the casing and the variation in hole sizes.

EFFECTIVE HOLES: STATISTICS OF PLACEMENT

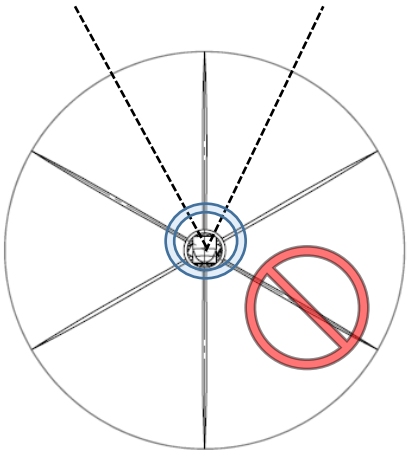


- For a 6 shot, 6 SPF, 60 deg Gun, the chance of placing a perforation hole in the preferred stress arc of the wellbore (up or down) is

50%

- The fully loaded 6 shot 60 deg cluster has the highest chance of any conventional fixed phase, fixed density system, which may explain the popularity of this system.

EFFECTIVE HOLES: DOWNLOADING

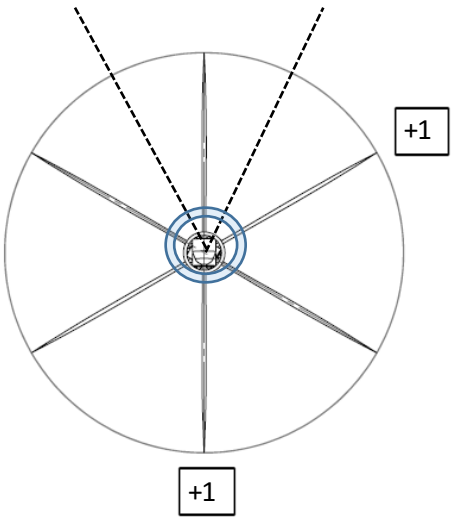


- The breakdown pressure of each cluster will vary with this statistic, like the flip of a coin: high or low.
- Downloading the 6 shot gun to 5 shots will affect the statistical chance of placing a shot appropriately, and increase the chance of variation from cluster to cluster.

68%

- It doesn't matter how you download.

EFFECTIVE HOLES: UPLOADING

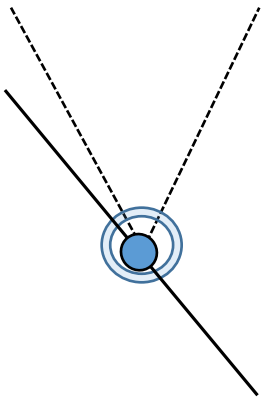


- Adding a shot to a constant phase system will not improve the chances.
- The seventh shot has a 16% chance to be in the top or bottom arc of interest.

50%

- It doesn't matter how you upload.
- The additional shot may further unbalance the clusters, if it moves more dominant holes to the low side.

EFFECTIVE HOLES: ORIENTING



+1

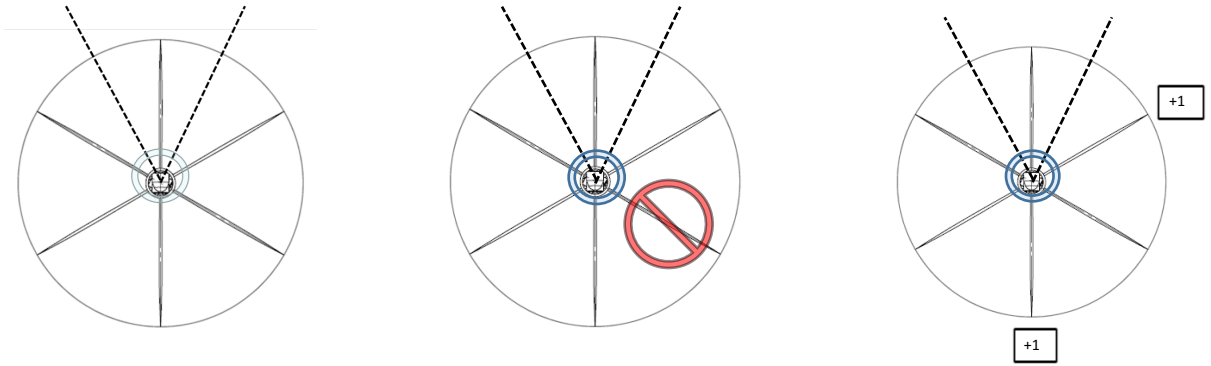
+1

- Orienting is a way to place charges in these clusters
- Eccentric weight bars are generally thought to have an accuracy of +/- 20 degrees, for an uncertainty of

25%

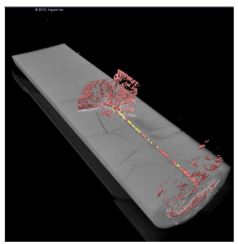
- This can be significantly increased by shooting on the fly, even to 100%

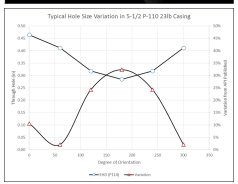
EFFECTIVE HOLES: CURRENT SYSTEMS

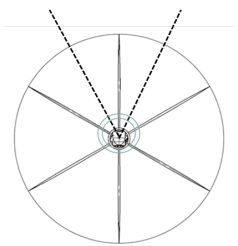


Downloading a constant phase gun results in lowered chance of optimal placement
Uploading a constant phase gun results in little improvement, unless a full phase is loaded

SUM OF PARAMETERS: TOTAL UNCERTAINTY







- The uncertainty inherent in each will stack:
- Perforation Geometry: 60%
- Perforation Hole Size: 40%
- Perforation Placement: 50%
- Reservoir and Well Variation: ??%

- Total Uncertainty: ~90%

- Parametric limited entry evaluation is difficult with this uncertainty
- Bonus: 25-100% uncertainty if orienting

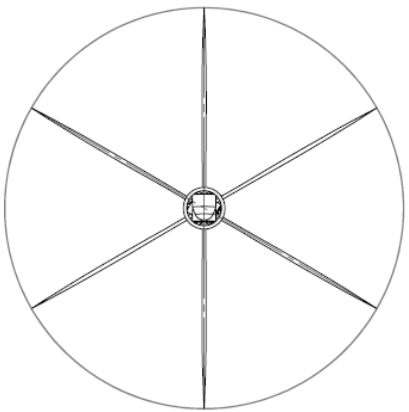
STATISTICAL DESIGN: NEW SYSTEMS

- Base Concepts – Charges
  - Charges may provide constant, improved tunnel geometry
  - Charges may provide constant hole size, with uniform tunnel geometry
  - Charges may provide highest possible economy
- Base Concepts – Gun Systems
  - Hole placement may be improved by phasing
  - Hole placement may be improved by orientation
  - For oriented and non oriented systems, there are designs that offer statistical improvement
  - Charge and gun work together to provide systemic tools for success
  - Gun systems can reduce the effect of hole size variation

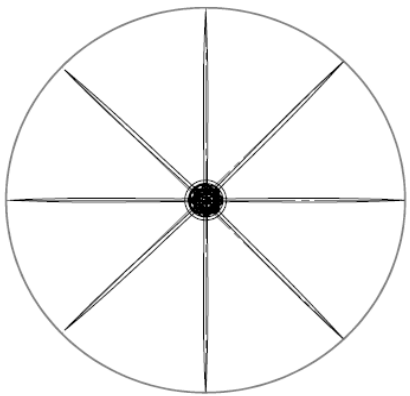
STATISTICS BASED DESIGN: GUN SYSTEMS

- Each gun is designed for an individual cluster
- The arrangement of charges is tuned so that
  - An additional charge in a cluster provides maximum benefit
  - A subtracted charge in a cluster yields minimum loss
- Systems are not constant phase or shot density, but target probability of placement with a given number of shots in a cluster
- For example: 2, 3, 4, 5, 6, 7, 10, 12, and 14 shot designs.
- Where lower number of shots are desired, orientation may be used, which impacts system design

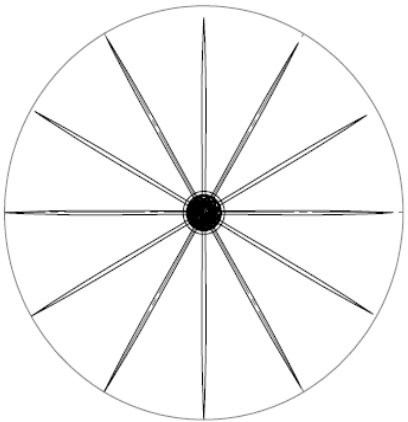
STATISTICS BASED DESIGN, WITHOUT ORIENTATION



6 Shot
U=50%



8 Shot
U=33%

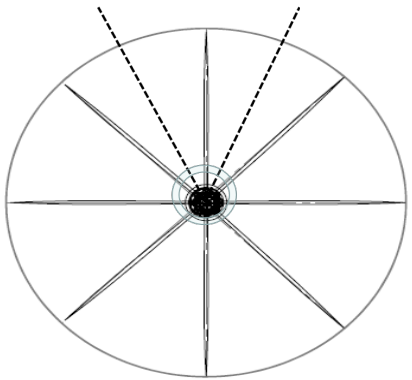


12 Shot
U=0%

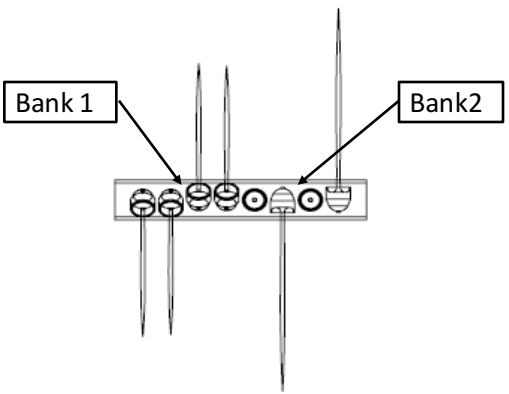
- Phased to improve perforation placement

STATISTICS BASED DESIGN: WITHOUT ORIENTATION

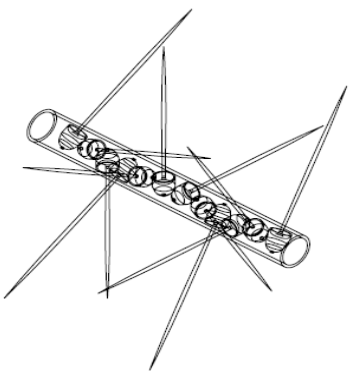
- Patent pending dual bank design groups opposing charges for best planar performance



8 Shot End



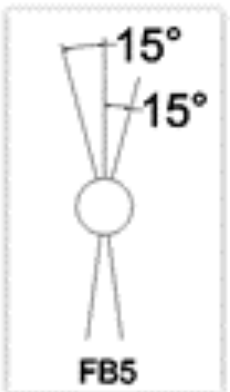
8 Shot Side



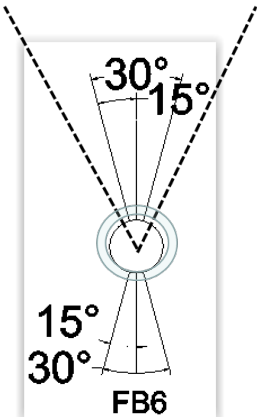
8 Shot 3D

STATISTICS BASED DESIGN WITH ORIENTATION

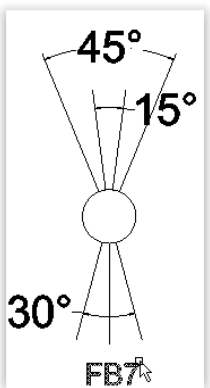
- Designed to be run with eccentric weight bar orientation



5 Shot
P=100%



6 Shot
P=100%

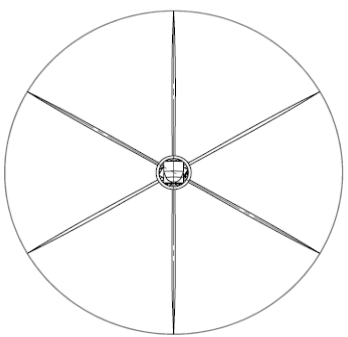


7 Shot
P=100%

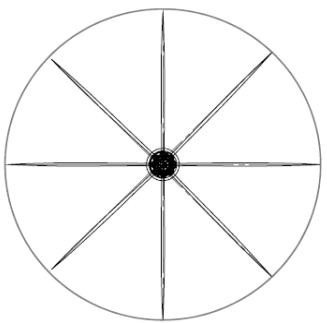
- Spread of charges offsets error orienting error

STATISTICS BASED DESIGN: PINPOINT ENTRY

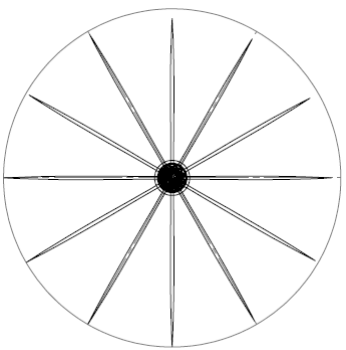
- Converging System
- Designed to be run without orientation
- Phasing to improve perforation placement



6 Shot
U=50%



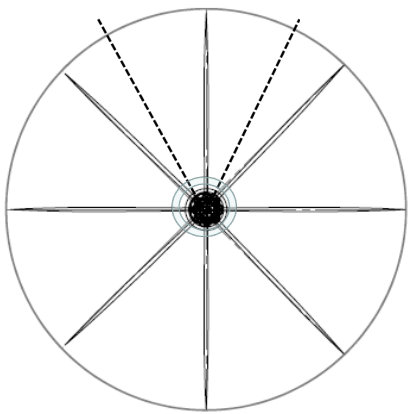
8 Shot
U=33%



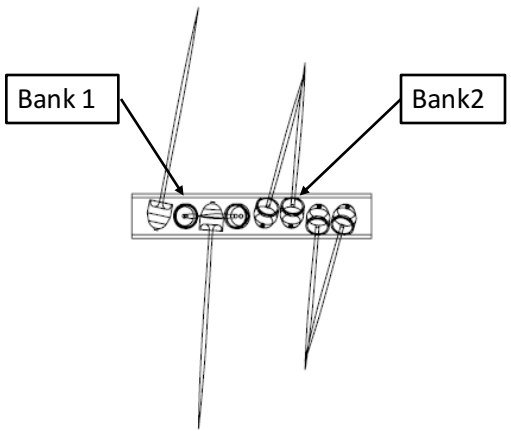
12 Shot
U=0%

STATISTICS BASED DESIGN: PINPOINT ENTRY

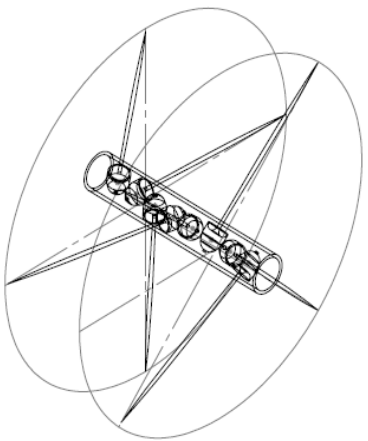
- Dual bank design groups opposing charges for best planar performance
- Converging charges offset hole size variation (Every perforation feeds a planar frac)
- Allows strategic arrangement of tip fractures



8 Shot End



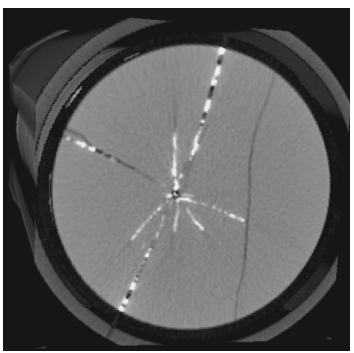
8 Shot Side

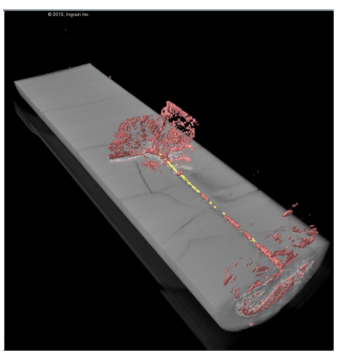


8 Shot 3D

CONTROLLED GEOMETRY CHARGES

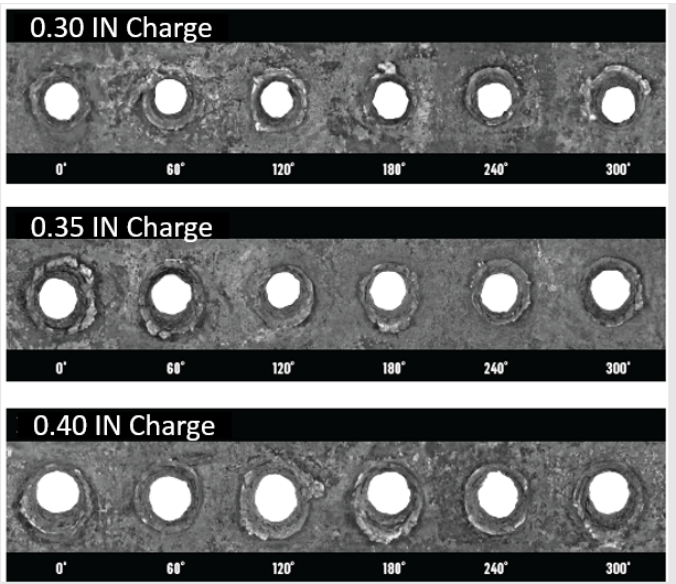
- Quality Controlled in Rock, Every Time
- Consistent Geometry delivered downhole
- Eliminates acid in some basins





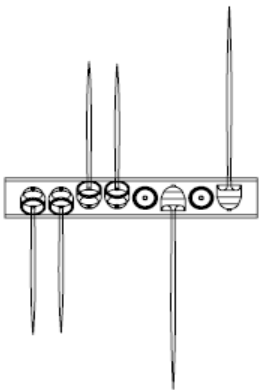
Fractured tip in shale
Energetic liner enhances geometry
Hole size variation is present,
Effectiveness increased with Converging SB System
For reaching beyond the nearest wellbore

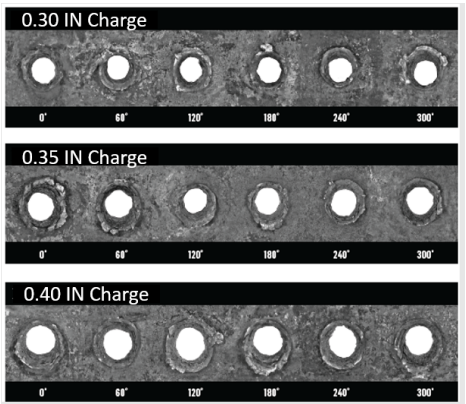
CONSTANT HOLE SIZE CHARGES



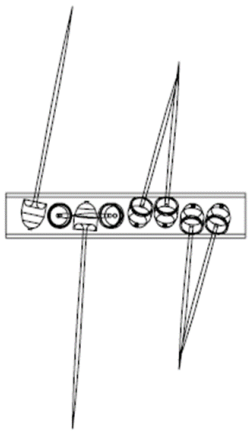
- Constant Hole Size Charge
- Parametric Hole Size Design: 0.30, 0.35, and 0.40 in.
- Performance independent of casing up to 5.5” 23 lb/ft P110
- Shorter, equal penetrations
- Engineered for maximum consistency

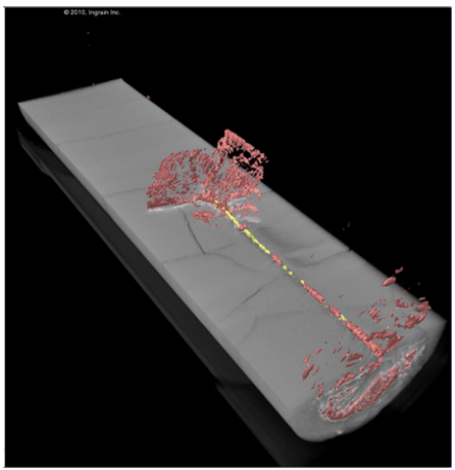
SOLUTIONS TO REDUCE ERROR
EQUAL ENTRY HOLE AND STATISTICAL PHASING



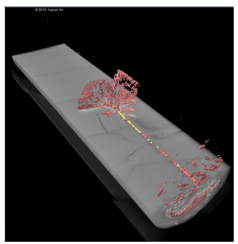


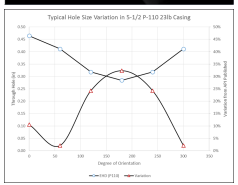
SOLUTIONS TO REDUCE ERROR
TUNNEL GEOMETRY AND PINPOINT ENTRY

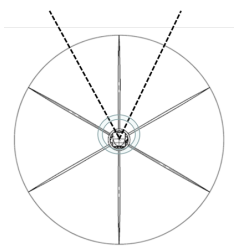




TOTAL UNCERTAINTY, REDUCED WITH DESIGN







- With the 8 Shot System:
  - Perforation Geometry: 3-10%
  - Perforation Hole Size: 3%
  - Perforation Placement: 33%
  - Reservoir and Well Variation: ??%
  - Total Uncertainty: ~35%
- With the 12 Shot System:
  - Perforation Geometry: 10%
  - Perforation Hole Size: 3%
  - Perforation Placement: 0%
  - Reservoir and Well Variation: ??%
  - Total Uncertainty: ~11%

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QUESTIONS? THANK YOU!

IPS 16-08

STATISTICS BASED SYSTEM DESIGN FOR PERFORATED CLUSTERS