QP2 CAGE DEVELOPMENT

Bob Ciarla, Reg Prostebby and Marshall Bales, Quinn Pumps
Saul Tovar and Billy Grandon, Oxy Petroleum Ltd.

INTRODUCTION

In July of 2003, Oxy Petroleum Ltd. (Clearfork RMT) approached Quinn Pumps to solve premature failures of existing cages used in their water flood fields for the Clearforks/Denver City Fields area. This area is renowned for having relatively deep wells, corrosive conditions and high water cuts (See Data Listed Below). Run lives for these cages were approximately 2 months using a regular pattern API SiN (Silicon Nitride) ball.

Data: Clearforks/Denver City Fields Area

Pump Sizes: 1.25" – 2 1/4"	API Oil: 33 Degree	Chlorides: 50-80,000
Stroke Length: 88" – 336"	Water Cut: 90+%	H_2S: 220 PPM
Tubing: 2 3/8" and 2 7/8"	Water SG: 1.06	CO_2: trace
Depth: 7200 – 8675 ft		pH: 6.2-7.3

ANALYSIS

The Engineers at Quinn Pumps gathered the required well information to try and come up with a solution to Oxy's short run life problem. In doing so, Quinn's reviewed several existing variations of rod pump Traveling and Standing Valve (TV and SV) cages that included competitors as well as its own cages. But, in order to make a large impact on the run lives of these wells, the Engineering Team at Quinn's realized they needed to make significant improvements to the TV and SV design for this project to be successful. These changes would include:

1. Improved Flow.
2. Reduced Change in Pressure (Delta P)
3. One Piece Cage.
4. Alternate Pattern Ball.
5. Improved Strength and Durability.

QP CAST CAGE DEVELOPMENT

Using typical Engineering techniques based on material and flow of cross-sectional areas, Quinn Pumps developed what they termed the QP Cage. The QP Cage (See Figure 1) is a One-Piece Cobalt cast cage that uses an alternate ball pattern. The type of Cobalt used gave this cast cage excellent corrosion resistance as well as superior strength that allowed it to be used in very deep wells (20000+ ft).

Based on cross-sectional diagrams (See Figure 2) the improved flow area using Quinn's new QP Cage was 6.6% over Company-A's Insert Guided (IG) Cage and 25% over Quinn's regular IG Cage. For the 1 ¾" prototype built, an alternate 1" silicon nitride (SiN) ball and four ball guides were used to increase the flow area plus reduce the amount of wear that occurred on the internal surfaces of the cast cage.

RAPID PROTYPING

Quinn's used Rapid Prototyping (See Figure 3) to build three QP Cages for field-testing. Rapid Prototyping is a technique used to create low quantities of cast parts before expensive molds are machined for mass production.

NEXT GENERATION TECHNOLOGY

The design of the QP Cage was a significant engineering challenge with the results pending field performance tests.

Rather than waiting for the QP Cage to be approved, and Quinn's Engineering Group to develop confidence in the new cage design, Quinn Pumps decided to advance to the next generation of technology that would significantly increase the confidence level of new designs.

Although the Engineers that designed the QP Cast Cage used existing engineering techniques to develop the first prototype, there were many unanswered questions pertaining to the performance of the cast cage. For example, analyzing a cross-section of the cage gives answers to questions raised at that location but, what about the effect of the design or the shape of the rest of the cage? The answers to these questions could not be obtained within a reasonable timeframe and most likely would only have a minimum degree of accuracy using basic hand calculations.

FINITE ELEMENT ANALYSIS (FEA) – QP2 DESIGN

As the first prototype of the QP Cage was being field-tested, Quinn Pumps made a significant investment in Finite Element Analysis (FEA) that allowed its Engineers and Designers to simulate the performance of parts and assemblies. This enabled much of the QP2 Cast Cage to be developed well before the first cage had completed it's field-tests.

The new QP2 Cast Cage was created using 3D-Modeling software then run through a series of FEA simulations.

Quinn's Engineering Department focused its new FEA design tool on locating the high stress areas, high wear areas, and streamline the flow of the QP2 Cast Cage using 3D models and that simulate known forces on the cage.

FEA ANALYSIS

Known forces were analyzed on the QP2 Cast Cage that revealed severe impact loads occurring on the internal ribs of the cage and axial loads caused by the operation of the pump (See Figures 4A and 4B).

Figure 4A reveals impact forces created high stresses due to the valve opening action and the ball radius colliding with a flat surface (Figure 5A) of the ball guide on the original QP Cage design. The ball guide was redesigned to match the surface of the ball (Figure 5B) and in doing so, the FEA Stress Analysis revealed a decrease in surface stress by 74%. Not only does this new design reduce the stress that occurs on the ribs but, the new shape significantly reduces ball rattle that can wear away at the ribs over extended periods. Severe ball rattle can also contribute to turbulence within the cage and promote gas breakout affecting the performance of the pump.

A second modification that is also shown in Figure 5B was made to the internal rib by "skirting" the bottom of the rib thereby increasing its surface area by approximately 70%. This is not considered a high stress area, but a high wear area due to the fact that as the ball moves down and the valve attempts to close, impacts will occur as the ball tries to seat itself.

PROTOTYPE RESULTS

Upon the return of two out of three original QP Cage prototypes, stress cracks and severe wear had occurred at the locations previously identified by FEA (See Figure 6).

Most downhole pump designers typically use similar techniques in determining the flow properties of a cage. One technique used in designing the original QP Cage was to take one or more cutaway sections and determine the flow based on the cutaway area. A second technique is to run fluid through a cage and compare the time required to drain a known volume of a reservoir. Both of these techniques work to a certain degree but leave several unanswered questions as to the performance of the cage and, more so, the performance of the cage with respect to its mating components. i.e. plug, ball, seat, and plunger.

Engineers can perform lengthy calculations in an attempt to replicate the performance of flow through a cage but as soon as complex shapes or other mating components are added the calculations increase exponentially.

In determining the performance of the QP2 Cage an assembly of mating components were 3-dimensionally modeled (Figure 8) to produce an accurate depiction of how the cage will perform. Fluid was then introduced into the model with an estimated density, viscosity, pressure, velocity, and surface finish that would closely depict an actual representation of pump operations.

The two FEA Analysis shown in Figure 8A and 8B, compare the change in pressure (Delta P) of the original QP Cage design to the next generation QP2 Cage design. In both analysis water was used as a medium with an inlet volume flow of 70 in^3/sec. The maximum and minimum pressure produced from the original QP Cage analysis was 47.974 psi and 8.43057 psi respectively. This gives a Delta-P of 37.54343 psi from the TV plug to 12 inches into the plunger. The maximum and minimum pressure produced from the QP2 Cage analysis was 36.1101 psi and 5.7816 psi respectively. This gives a Delta P of 30.3285 psi from the TV plug to 12 inches into the plunger.

Comparing the two Delta-P values, 37.54343 psi for the QP Cage and 30.3285 psi for the QP2 cage, the Delta-P was decreased by approximately 19% in the QP2 Cage. This value represents the resistance to flow through the QP2 Cage has decreased by 19%.

As each iteration of FEA Analysis was being performed several modifications were introduced to the next generation of the QP2 cast cage (See Figure 8B). These were subtle modifications introduced to the radii and shape of the internal faces of the cage so that pressure anomalies such as spikes and vacuums were minimized. These pressure anomalies are indicated with arrows from the FEA Analysis in Figure 8A to show where turbulence and cavitation have a high chance of occurring. In designing the QP2 cage these areas have been identified and reduced to a point of negligible effect. Reducing the turbulence and the chance of cavitation reduces the possibility of washing and gas breakout. With the reduction of washing and gas breakout the cage and its mating components will last longer and perform more efficiently.

CHANGE IN PRESSURE – DELTA-P

The Delta-P is one of the most important features of designing pump components where flow is involved. In one sense, a high Delta-P is a desirable feature manipulated by rod pumps to move fluid from a high-pressure to a low-pressure location. This is one of the main premises that rod pumps operate with to move fluid. Lets not confuse this with flow through the pump. Regarding the components of the pump a low Delta P is extremely desirable when completing an FEA Analysis. The pump components that create a resistance to flow will increase the work requirements and the required Delta-P to move fluid through the pump. In “Layman’s” terms, if the pump has a low flow resistance, or low Delta-P, then the change is pressure used to move fluid through the pump to surface can be reduced to move the same amount of fluid. This Delta-P improvement will result in the movement of more fluid to surface by the pump, decreased operating costs, or both.

COMPARISON

In order to justify the quality of the QP2 Cast Cage a comparison was completed using the QP2 Cast Cage, two of Quinn’s competitor’s cages, and two of Quinn’s original candidates that were chosen to solve short run life problems. Because of proprietary information and the fact that Quinn Pumps is not interested in discrediting or disclosing information about its competitors the data collected regarding two of the cages compared was omitted from this paper.

In this comparison three 1.75” cage assemblies (Company-A, Quinn IG, and QP2 Cage) have been created and analyzed to compare the performance of each of these cages using FEA Analysis. Relevant information taken from the analysis include:

1. Flow Performance.
2. Pressure Performance.
3. Velocity Performance.
4. Average Fluid Velocity.
5. Flow Time Through Assembly.

FLUID SIMULATION:

Fluid Type:	Water
Inlet Volume Flow:	30 in^3/sec
Outlet Static Press:	1 ATM

COMPARISON RESULTS:

FLOW PERFORMANCE RESULTS: COMPANY-A, IG CAGE, QP2 CAST CAGE
(See Figures 9A, 9B, and 9C)

PRESSURE PERFORMANCE RESULTS: COMPANY-A, IG CAGE, QP2 CAST CAGE
(See Figures 10A, 10B, and 10C)

The results of Figures 10A, 10B, and 10C help designers to point out specific locations of pressure spikes and drops that are unavoidable pump characteristics but undesirable anomalies.

VELOCITY RESULTS: COMPANY-A, IG CAGE, QP2 CAST CAGE
(See Figures 11A, 11B, and 11C)

This table indicates the velocity of particles through their assemblies and the average time it takes for these particles to travel from inlet to outlet.

COMPILED RESULTS

In order to simplify the process of determining the best overall cage, each analysis has been broken down and rated numerically. Values have been micro analyzed and filtered to remove irrelevant data. Depending on what you are looking for, the qualities of each cage may be rated differently.

1. From the FEA Flow Performance color plots predicting gas breakout areas were analyzed. Cages have been rated from 1 – 3 with 1 being the least amount of gas breakout.

1. QP Cage –	Range:	14.6853 – 14.729	(ΔP=0.0437 psi)
2. Company-A –	Range:	14.5089 – 14.8589	(ΔP=0.3500 psi)
3. IG Cage –	Range:	13.8016 – 14.7355	(ΔP=0.9339 psi)

2. Pressure graphs were analyzed. It was determined that for the majority of fluid, high peaks and low valleys are undesirable features as fluid passed through the assembly. Ratings are from 1 – 3 with 1 being the most desirable.

1. QP Cage –	Range:	14.74 – 14.94	(ΔP=0.20 psi)
2. Company-A –	Range:	14.60 – 14.86	(ΔP=0.26 psi)
3. IG Cage –	Range:	14.76 – 15.05	(ΔP=0.79 psi)

3. Velocity graphs were analyzed. It was determined that for the majority of fluid, constant velocity is the most desirable feature as fluid passes through the assembly. Ratings are from 1 – 3 with 1 being the most desirable.

1. QP Cage –	Range:	10 – 63	(ΔV=53 in/sec)
2. Company-A –	Range:	15 – 70	(ΔV=55 in/sec)
3. IG Cage –	Range:	10 – 67	(ΔV=58 in/sec)

FIELD TEST RESULT:

Up until the published date of this technical paper there have been 9 rapid prototypes field-tested with the cooperation of Oxy Petroleum Ltd. Three of these tests were completed using the original QP Cast Cage and six tests were completed using the next generation QP2 Cast Cage. The results are presented below with the "Date" representing when the cage was placed in service.

RAPID PROTOTYPE

QP Cast Cage	Date	Results	Performance
1. 1 ¾" Field Test	May 28, 2004	Still in Operation.	20 months.
2. 1 ¾" Field Test	June 18, 2004	Pulled for Rod Part. Cage wear OK. Sent for Analysis.	2 months.
3. 1 ¾" Field Test	June 20, 2004	Cage Failure. Seat Plug backed-off and Cracked.	28 Days.

<u>QP2 Cast Cage</u>	<u>Date</u>	<u>Results</u>	<u>Performance</u>
1. 1 ¾" Field Test.	Nov 24, 2004	Still in Operation.	14 months.
2. 1 ¾" Field Test.	Dec 21, 2004	Still in Operation.	13 months.
3. 1 ¾" Field Test.	Dec 22, 2004	Still in Operation.	13 months.
4. 1 ¾" Field Test.	March 5, 2005	Failed in 1 day. Flaw in Rapid Prototype.	1 Day.
5. 2" Field Test.	April 21, 2005	Still in Operation.	9 months.
6. 2" Field Test.	May 27, 2005	Failed in 1 day. Flaw in Rapid Prototype.	1 Day.

<u>CAST CAGE FROM MOLD</u>

<u>QP Cast Cage</u>	<u>Date</u>	<u>Results</u>	<u>Performance</u>
1. 2" Cast	Nov 9, 2005	Still in Operation.	66 Days.
2. 2" Cast	Nov 9, 2005	Still in Operation.	66 Days.
3. 2" Cast	Nov 10, 2005	Still in Operation.	65 Days.
4. 2" Cast	Nov 17, 2005	Still in Operation.	58 Days.
5. 2" Cast	Nov 29, 2005	Still in Operation. Pulled Dec 30 for Equip. Change. Looks New!	45 Days.
6. 2" Cast	Dec 20, 2005	Still in Operation.	24 Days.
7. 2" Cast	Dec 21, 2005	Still in Operation.	23 Days.
8. 2" Cast	Dec 21, 2005	Still in Operation.	23 Days.
9. 2" Cast	Dec 30, 2005	Still in Operation.	15 Days.
10.2" Cast	Jan 12, 2006	Still in Operation.	2 Days.

<u>DISCUSSION – RAPID PROTOTYPES</u>

The original QP Cast Cage designs produced five 1 ¾" rapid prototypes to be used in traveling valve assemblies. Two of the five prototypes were pulled from the list of potential field-tests due to visual surface porosity that may cause premature failure. The other three rapid prototypes began field-testing with Oxy Petroleum Ltd. on May 28, 2004. Of the three rapid prototypes one has been performing for 20 months and is still in operation.

The second rapid prototype field-tested lasted 28 days. It was pulled due to cage failure and then sent for analysis to Quinn Pumps laboratory in Red Deer, Alberta. An analysis of the cage determined that although the QP Cage had seen severe wear and some deformation to the ball guides, failure had occurred due to the seat cracking and then washing caused by continued pumping. The QP Cage could have continued to operate but without the seat intact the valve could not maintain pressure and therefore pump operation could not continue.

The third 1 ¾" prototype was pulled from use when a rod had parted in the well after the QP Cage had run for 2 months. Because the opportunity to analyze another field-tested prototype had transpired, the cage was retrieved and sent to the Quinn Pumps lab in Red Deer, Alberta. The results showed some wear and deformation had occurred on the internal ball guides of the cage but the damage was minimal and the cage could have continued to perform pumping operations for an indefinite period of time. The cage was not re-run.

Once the designs and FEA analysis were complete for the QP2 Cast Cage, ten more rapid prototypes were produced for field tests. Four of the ten cages were pulled from the list of potential field tests due to severe porosity in critical locations during visual inspection. Four 1 ¾" and two 2" QP2 Cast Cages were field-tested beginning on Nov 24, 2004. Of the six rapid prototype cages tested, four are still in operation with the longest operating for 14 months.

Two of the QP2 Cast Cages (One 1 ¾", and one 2") failed within one day of well operations. These two cages were sent to Quinn Pumps lab in Red Deer immediately after the failure occurred. It was determined that at critical locations in the cage undersurface porosity had occurred in both cases causing catastrophic failure.

DISCUSSION – CAST CAGES FROM MOLD

Between Nov 9, 2005 and Jan 12, 2006 ten QP2 Cast Cages created from a machined mold have been run in pumping operations for Oxy Petroleum Ltd. No failures have yet to occur.

CONCLUSION

The design of the QP2 Cast Cage was completed as of June 2005. Two catastrophic failures of rapid prototypes were determined to be caused by internal flaws or anomalies at critical locations under the surface of the castings. These two failures had placed some doubt in the minds of all those involved in the project but with the proper information and laboratory analysis the source of the failures was determined not to be due to the Engineering Design of the QP2 Cage.

Five of the eight rapid prototypes field-tested are still in operation to this day greatly meeting and exceeding all expectations of performance. With the use of Finite Element Analysis Quinn Pumps was able to maximize the strength, flow, and durability of its next generation QP2 Cast Cage design. FEA was also a key instrument in allowing designers at Quinn Pumps to compare the performance of the original QP Cage design to the next generation QP2 Cage design before field-testing was complete. This significantly reduced the timeframe required for the QP2 Cage to be properly and confidently released for production. It also allowed designers to measure the performance of this cage in ways that cannot be physically measured even with mechanical test units. But at the other end of the spectrum, a simulation cannot completely replicate the exact situation of pump production and data extracted from an FEA simulation is only as accurate as the information placed in the simulation.

A mold for the 2" QP2 Cast Cage was built and ten of these cast cages have been placed in service. Up until the time of this paper the QP2 Cages have been operating for 2 to 66 days with 100% success rate. One cage was pulled and looked at on Dec 30, 2005 after operating for 32 days. The pump pull was due to an equipment change and gave Quinn's an opportunity to check the performance of the QP2 cage. The cage looked new with little or no evidence of wear or deformation and was then run into the same well that has now been running for 45 days and continues to operate.

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ACKNOLEDGEMENTS

On behalf of Quinn Pumps, I would like to thank Oxy Petroleum Ltd. for allowing Quinn's the opportunity to develop and test the QP and QP2 Cages in its wells.

Table 1
Flow Performance

CAGE	Max Press (psi)	Min Press (psi)	Delta P (psi)	Length (in)
Company-A	15.2089	14.3339	0.875	13
Insert Guided	16.6033	11.9338	4.6695	19.50
QP2 Cage	15.0352	14.5978	0.4374	16 5/8

Table 2
Velocity Performance.

Average Velocity:	Company-A:	37.2 in/sec	Flow Time:	0.349 sec
	IG Cage:	47.5 in/sec		0.411 sec
	QP2 Cage:	42.0 in/sec		0.396 sec

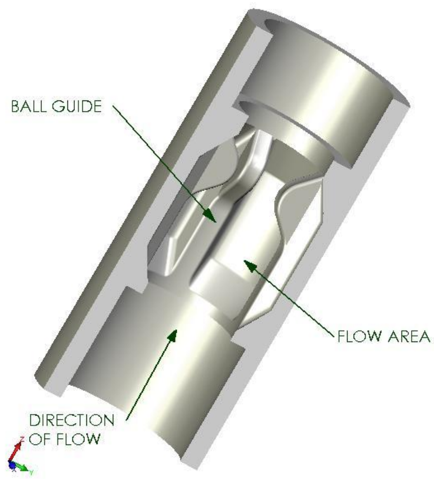

Figure 1 - The QP Cage

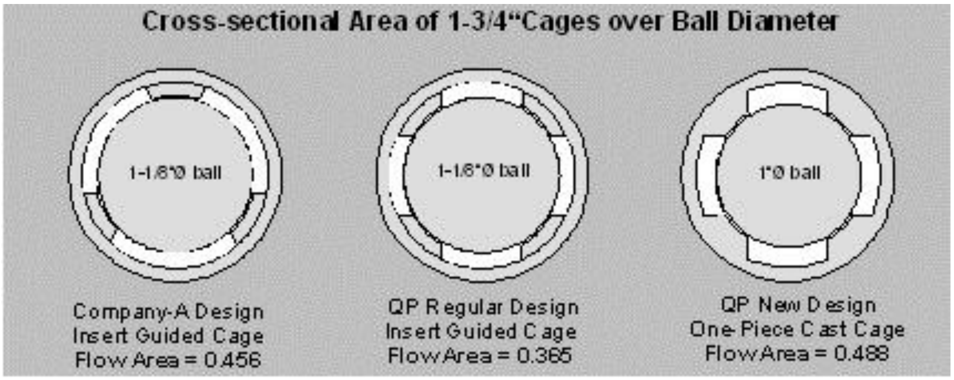

Figure 2 - The Cross Sectional Flow Area

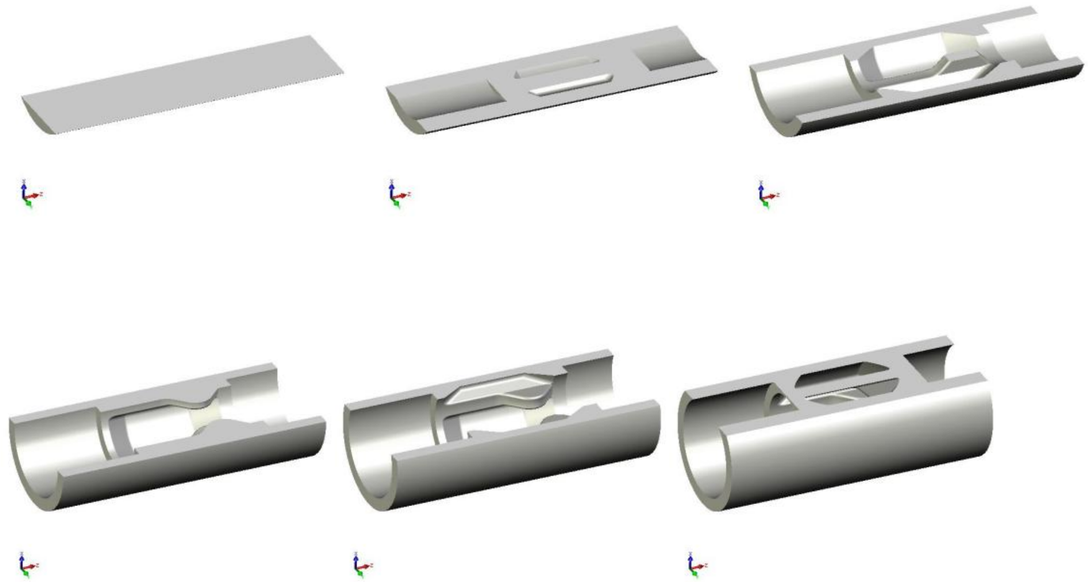

Figure 3 - Rapid Prototyping

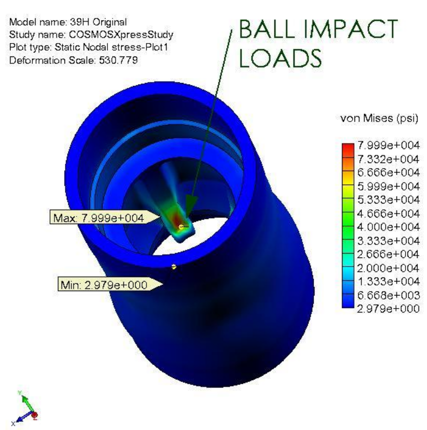

Figure 4A - FEA Analysis Ball Impact

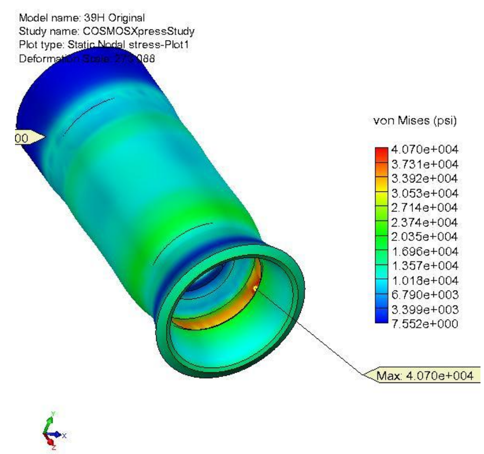

Figure 4B - FEA Analysis Axial Loading

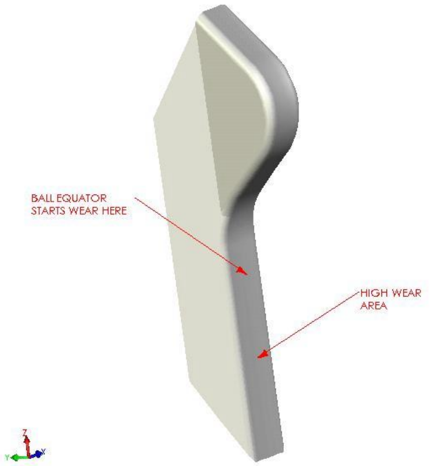

Figure 5A - Original QP Ball Guide

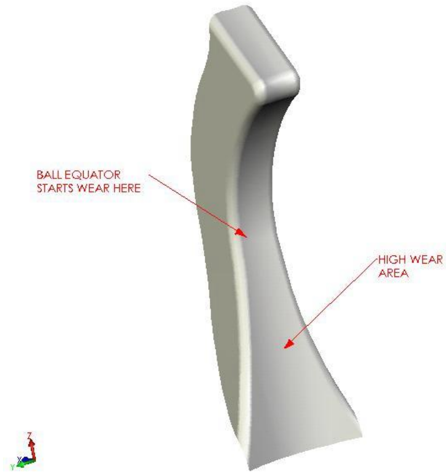

Figure 5B - QP2 Cage Ball Guide

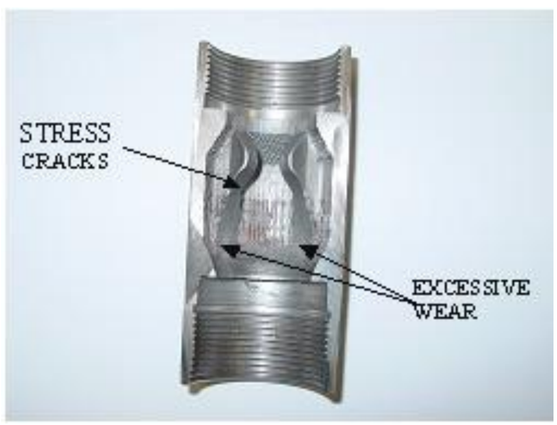

Figure 6 - QP Cage Prototype

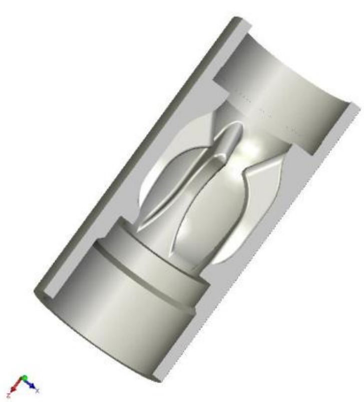

Figure 7 - QP2 Cast Cage

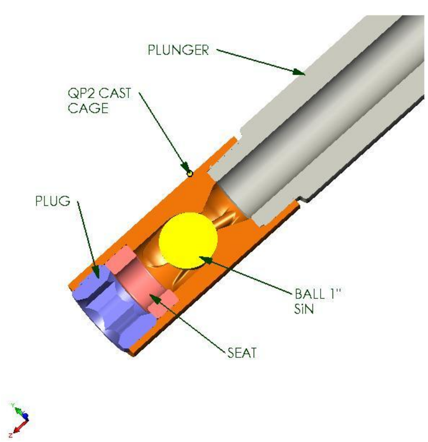

Figure 8 - QP2 Cast Cage Assembly

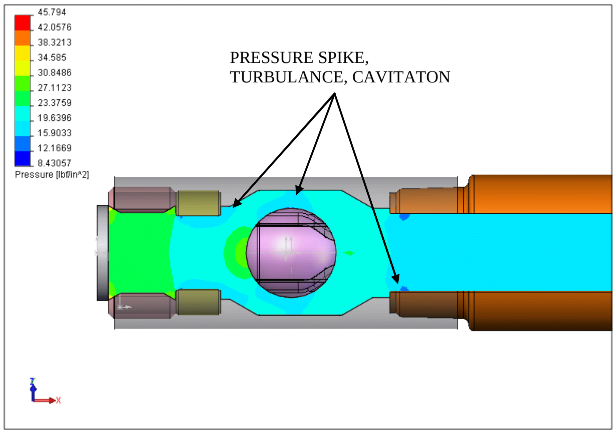

Figure 8A - Original QP Cast Cage

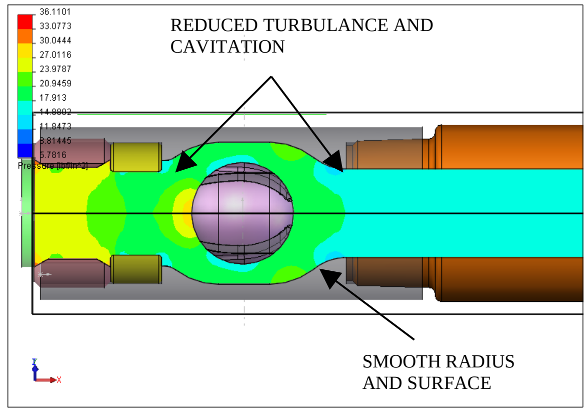

Figure 8B. QP2 Cast Cage

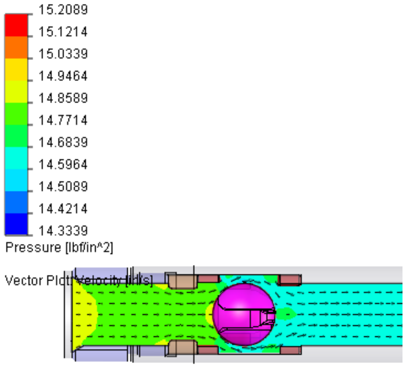

Figure 9A - COMPANY-A – Detail

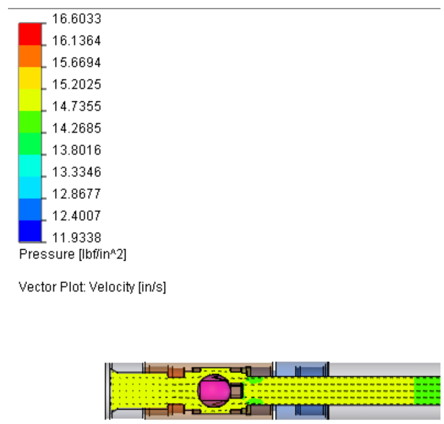

Figure 9B -IG Cage – Detail

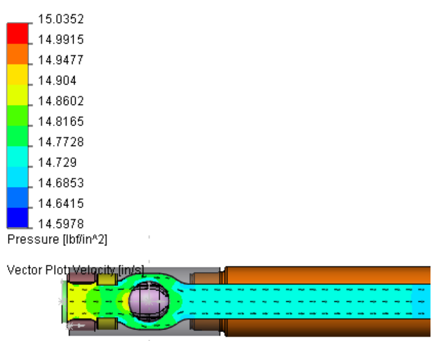

Figure 9C - QP2 Cage – Detail

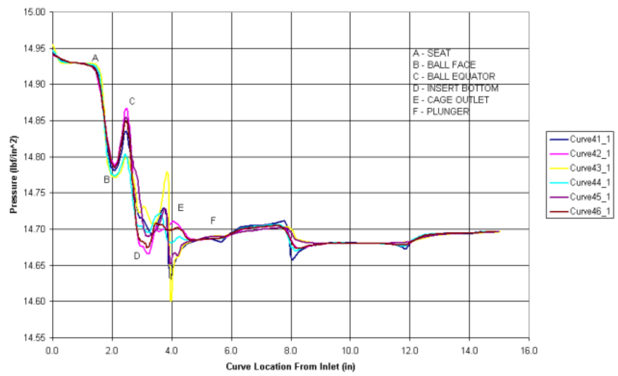

Figure 10A - Company-A – Pressure

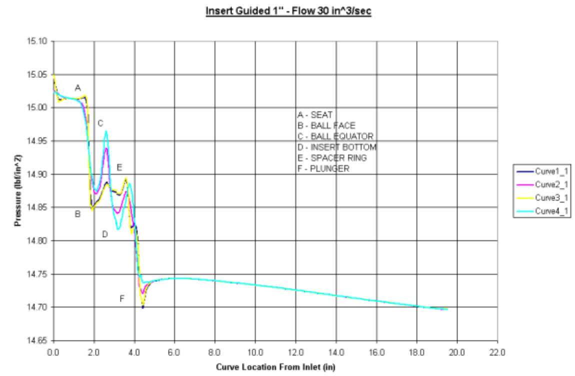

Figure 10B - IG Cage – Pressure

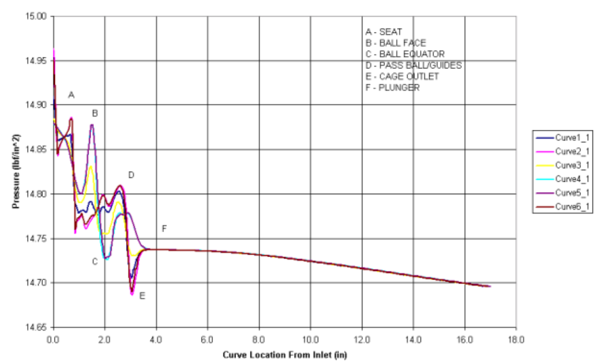

Figure 10C - QP Cage – Pressure

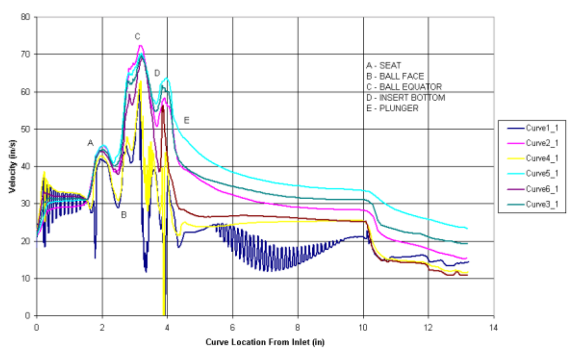

Figure 11A - Company-A – Velocity

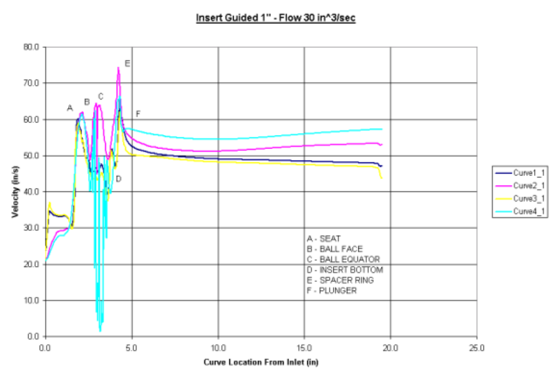

Figure 11B - IG Cage – Velocity

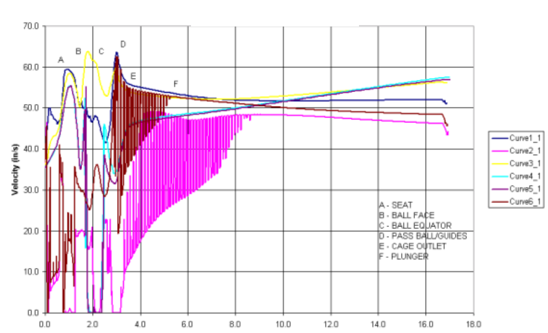

Figure 11C - QP2 Cage – Velocity