PREMIUM TECHNOLOGY CONNECTION DESIGN AND LABORATORY TESTS

Matías Pereyra, José Villasante
Tenaris

ABSTRACT

With the aim of developing a more reliable connection to be used in the current artificial lift systems, Tenaris has worked in an innovation process whose outcome was the premium connection product family for sucker rods.
This paper explains the comparison between the premium connection design and the API connection design through finite element analysis methods, the product validations full scale tests for beam pumping and progressive cavity pumping, and the application recommendations.

INTRODUCTION

Standard API Connection design and its limitations

The beam pumping is the most commonly used system to produce oil in the world. Through this system, the sucker rod string transmits an alternative movement from the surface to the bottom hole pump, to lift the produced fluid. This alternative movement creates alternative stresses in the string and its connections.
The most used connection design is the API connection with a cylindrical thread profile, one flank contact with no diametrical interference requiring high axial interference to maintain the connections properly made-up during its well service; if the required axial interference is not reached, the connection may loosen causing early fatigue failures
The make-up high axial interference and the thread profile geometry creates non-uniform stress distribution that when added to the well working loads limits the API connection capacity to withstand high axial fatigue loads.

PREMIUM CONNECTION DESIGN FOR BEAM PUMPING

Finite Element Analysis comparative design

With the aim of developing a connection capable of withstanding high axial fatigue loads, a finite element analysis (FEA) design process was carried out at Tenaris R&D center.
The API[1, 2] connection was meshed and its stress and strain distributions for make-up and maximum working loads were obtained, these results were used to compare against the new design.
Several new geometrical alternatives (taper, pitch, flank angles, diametrical interference) were studied for the new connection, by running FEAs and comparing its resulting stresses and strains against the API design (See Figure 1).
The outcome was a tapered connection with flank to flank contact thread and diametrical interference to avoid the loosening tendency of API design

Fatigue Damage Criterion

In order to predict the fatigue performance of the connections during the design stage, the Sines[3, 4] method was adopted. This method is valid for simple multiaxial stress cases where the principal alternative stresses do not change their directions relative to the stress part.
The fatigue indicator is calculated using the following formula:

$$D = \frac{\frac{T}{3} - \overline{\sigma_m}}{\sigma_a}$$

Where:

D: fatigue indicator
T: Minimum Tensile Strength (psi or MPa)

$\overline{\sigma_m}$: Mean stress (psi or MPa) $$\overline{\sigma_m} = \frac{S_{m1} + S_{m2} + S_{m3}}{3}$$

Smi: Mean component of the principal stress (psi or MPa) $$S_{mi} = \frac{S_{i.máx} + S_{i,mín}}{2}$$

σ_a : Alternative Stress (psi or MPa) $$\sigma_a = \frac{[(S_{a1} - S_{a2})^2 + (S_{a2} - S_{a3})^2 + (S_{a3} - S_{a1})^2]^{1/2}}{\sqrt{2}}$$

Sai: Alternative components of the principal stress (psi or MPa) $$S_{ai} = \frac{S_{i.máx} - S_{i,mín}}{2}$$

Si max: Max component of the principal stress (psi or MPa).
Si min: Min component of the principal stress (psi or MPa).

In the zones where the fatigue indicator is larger than 1 (D>1) the connection will not be susceptible to fail due to fatigue; in the areas where the fatigue indicator is lesser than 1 (D<1), the connection will be susceptible to fail. Five critical connection zones where selected (see Figure 2), and the fatigue indicator was calculated from the edge to the center of the section. Results show that the Premium Connection fatigue coefficients distribution is better than the API connection showing more positive results in critical areas as the first engaged tooth (see Figure 3).

Laboratory full scale tests

To validate the predicted results, samples of the new premium connection were manufactured and axial fatigue tests were carried out. Each fatigue test consists of applying a cycle of minimum and maximum axial loads to the sample; if the sample reaches to 10million cycles without breaking, it means that the sample is loaded under the connection fatigue limit and will not fail at this loading; however, if it brakes at less than 10 million cycles, it means that this load exceeds the connection fatigue limit.

Fatigue samples consisted of two pony rods (2 ft length) with pin ends joined with a coupling. Pony rods were manufactured with larger body than the nominal size of the pin thread in order to induce the failures in the connection instead of the rod body.
Rod body material: 4142 Mod steel, D grade (Yield Strength 85Ksi min, Ultimate tensile strength 115 to 140Ksi)
7/8" rod body with 3/4" premium connections
11/8"rod body with 7/8" premium connections
1 1/8" Rod body with 1" premium connection pin
Couplings: 8630 UHS Premium Connection

All the connection sizes were tested up to a maximum load that equals the minimum material yield strength and the premium connection design reached to 10million cycles (infinite life); under the same condition, API connection samples failed at less than 5million cycles (See Tables 1 and 2). This results shows that the premium connection design can withstand as much fatigue load as the rod body and outlasts the API connection design under high fatigue load conditions.
To determine the Goodman curve equation to be used in the well design of premium connections, the rod body fatigue limit was determined with axial fatigue tests. The tests loads were determined using Minimum to Maximum Stress ratio of 0.1 and, after applying a safety margin, a new maximum alternative stress for the premium connection design was defined. It almost doubles the API maximum alternative stress (100% Goodman diagram) for the D grade sucker rod (see Figure 4).
The new equation for the D grade Premium Connection maximum allowable stress is:

$$\mathrm{Sa} = \left(\frac{\mathrm{UTS}}{2.3} + 0.375 \times \mathrm{Smin} \right) \times \mathrm{SF}$$

Where:
Sa: Maximum allowable stress (psi or MPa)
Smin: Minimum stress (psi or MPa)
UTS: Sucker Rod Ultimate tensile strength (psi or MPa)

SF: Service Factor

PREMIUM CONNECTION FOR PROGRESSIVE CAVITY PUMPING

Finite Element Analysis

Sucker rods are normally also used to drive progressive cavity pumps, in this application they should withstand torque and axial load.
An equivalent stress as a result of combined loading can be calculated by using the Von Mises equation[5].

$$\sigma_e = \sqrt{\frac{C_1 L^2}{\pi^2 D^4} + \frac{C_2 T^2}{\pi^2 D^6}}$$

Where:

$\sigma_{e=}$ Effective Stress
L= Axial load (lbs or N)
T= Total Torque (ft*lbs or N*m)
D = Rod body outer diameter (in or mm)
C_1= Constant (Imperial Units$1.6x10^{-5}$, International Units 16)
C_2= Constant (Imperial Units 0.1106, International Units $7.680x\ 10^{8}$)

A Three dimensional Finite Element Analysis mesh was developed to simulate combined torsion plus tension loads and to analyze the stress distribution on the connections.
The premium connection showed that even with yield on the rod body, the stress distribution through the connection profile is homogeneous and that rod body will fail before the connection

Laboratory full scale tests

Torsion to failures and combined tension plus torsion to failure tests were carried out in order to determine the connection performance for PCP applications

The samples used to run the tests were manufactured using larger rod body diameters than the connection nominal size:
Rod body material: 4142 Mod steel, D grade (Yield Strength 100Ksi min, Ultimate tensile strength 115 to 140Ksi)
1"rod body with 7/8" premium connections
1 1/8" Rod body with 1" premium connection pin
Couplings: 8630 UHS Premium Connection

Pure torsion tests

After the connection hand tight, increasing torque to failure is applied.
The results are connection yielding and failure torques, the yielding torque is also used to define the make-up torque for the combined load tests.
A continuous record of torque and turns is kept.

Results:
7/8" DPC yielding torque 1050 ft*lbs; failure torque 1300 ft*lbs
1" DPC yielding torque: 1700 ft*lbs; failure torque 1900 ft*lbs

Combined Tension plus torsion to failure

The connection is made-up to a 90% of its yielding torque (determined out of pure torsion tests)
Apply the required axial loads (40000 lbs for 7/8" DPC samples and 50000 lbs for 1" DPC samples)
Apply increasing torsion to failure.
A continuous record of axial load, torque and turns is kept.

Results:
1" Rod body with 7/8" Premium Connection yield torque 900ft*lbs with 40000lbs of axial load (see Figure 5)
11/8" Rod body with 1" Premium Connection yield torque 1500ft*lbs with 50000lbs of axial load (see Figure 6)

Considering the Von Mises equation and a 100 ksi of Yield Strength of the Grade D4142, these results can be compared to theoretical predictions in order to determine if the connection can withstand as much load as the rod body

7/8” Rod body @ 40000lbs……..Yield torque: 475 ft*lbs
1” Rod body @40000lbs……….Yield torque: 810 ft*lbs

1” Rod body @50000lbs……….Yield torque: 730 ft*lbs
1 1/8” Rod body @50000lbs……Yield torque: 1170 ft*lbs
1 1/4” rod body @50000lbs……..Yield torque: 1680 ft*lbs

7/8” D Premium Connection withstands higher loads than 7/8” and 1” D4142 Rod body.
1” D Premium Connection withstands higher loads than 1” and 1 1/8” D 4142 Rod body
1” D Premium Connection withstands 90% of the 1 1/4” D 4141 rod body

CONCLUSIONS

Beam pumping characterization:

The Premium Connection fatigue limit is higher than the rod body, which means that the connection is 100% efficient for fatigue loads

The Premium Connection showed higher fatigue life than API design in fatigue tests at high loads.

Progressive cavity pump characterization:

Tension plus torsion to failure tests show that the 7/8” and 1” Premium connections show higher Yielding torque than its rod body.

Larger rod body diameters can be used with Premium Connection increasing the flow efficiency of the string in PCP applications.

REFERENCES

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3. E.L. Hoffman, “Finite element analysis of sucker rod couplings with guidelines for improving fatigue life”, SAND97-1652.UC-122, Sandia National Laboratories. USA. Sept, 1997.
4. K.J. Bathe, “Finite Element Procedures”, Prentice Hall. 1996
5. PC Pumping Systems: Design, Operation and Performance Optimization C-Fer Technologies, Canada. Apr, 2002.

Table 1
Axial fatigue test results 3/4” connections

	API 3/4”		**Premium Connection 3/4”**		
Maximum Load (Ton)	15	15	15	16	17
Minimum Load (Ton)	5		5		
% Goodman	279.8		279.8	308	336
Cycles (Million)	2.96 Pin failure	4.87 Pin failure	10 No failure		

Table 2
Axial fatigue test results 7/8” connection

	API 7/8”		**Premium Connection 7/8”**							
Maximum Load (Ton)	22	22	16	16.5	17	17.5	18	22	23	24
Minimum Load (Ton)	5		5							
% Goodman	300.7	300.7	194.6	203.4	212.3	221.2	230	300.7	318.7	336
Cycles (Million)	1.4 Pin failure	1.271 Coupling failure	10 No failure							

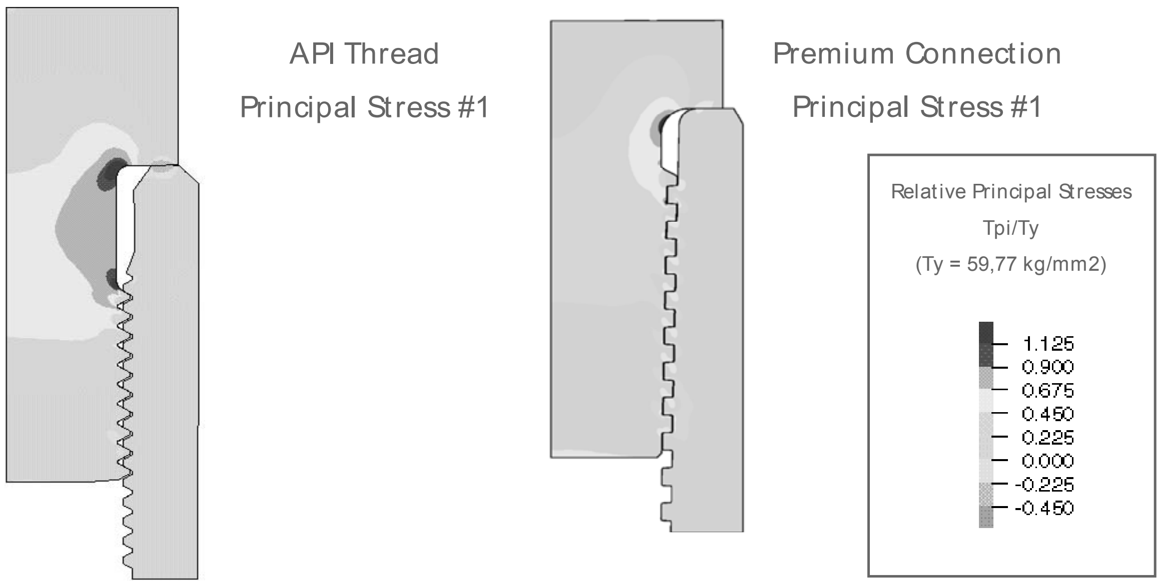

Figure 1- Finite Element Analysis comparing API with Premium Connection design, load of 100% Goodman (D Grade).

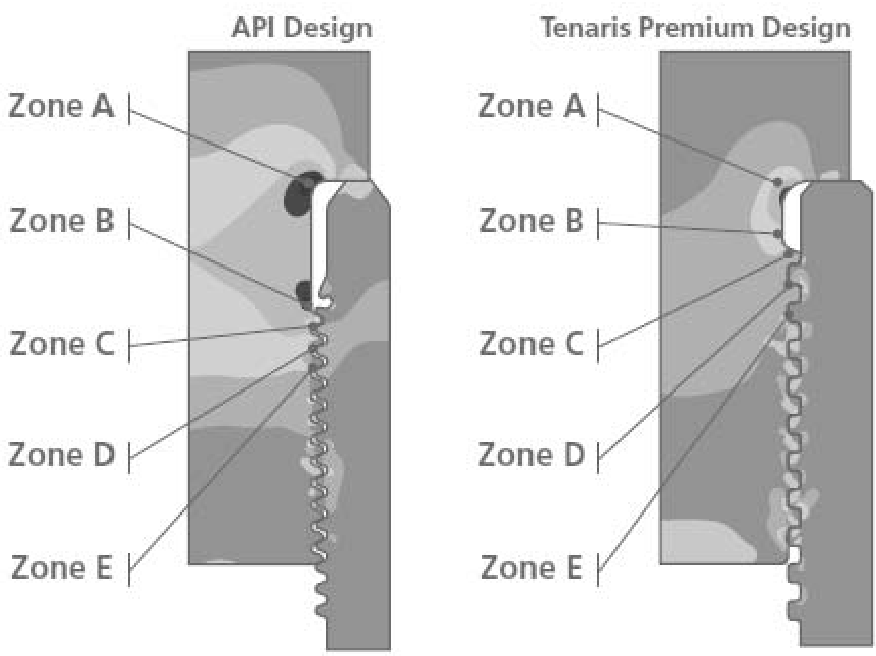

Figure 2 - Zones Where Fatigue Coefficient is Evaluated to Compare Fatigue Behavior of API with Premium Connection Designs

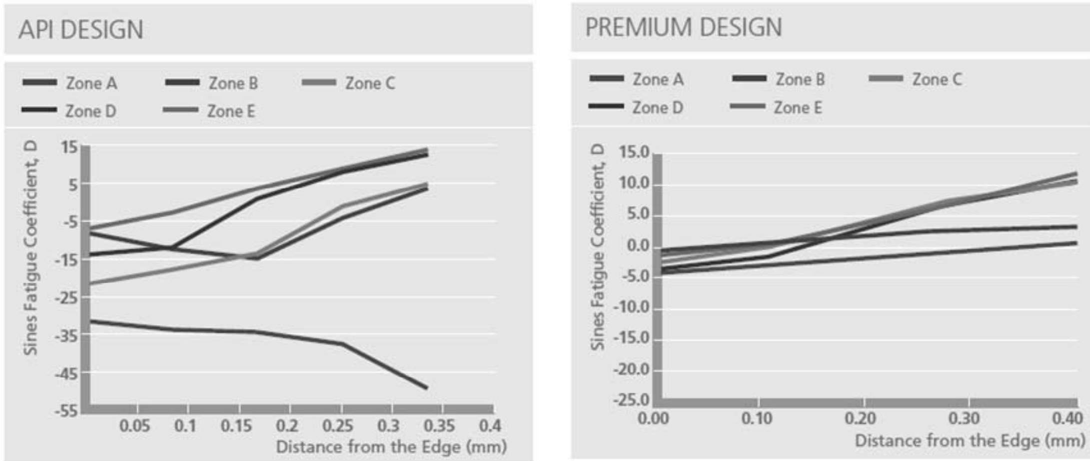

Figure 3 - Sines fatigue coefficient distribution for API and premium connection designs.

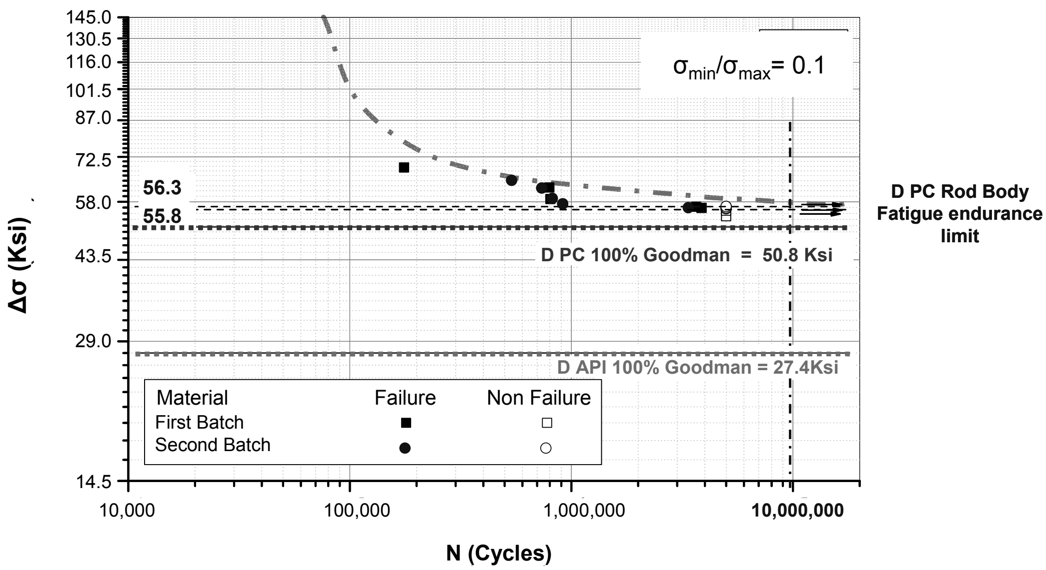

Figure 4 - Rod Body Fatigue Curve Steel D 4142 Used with Premium Connections

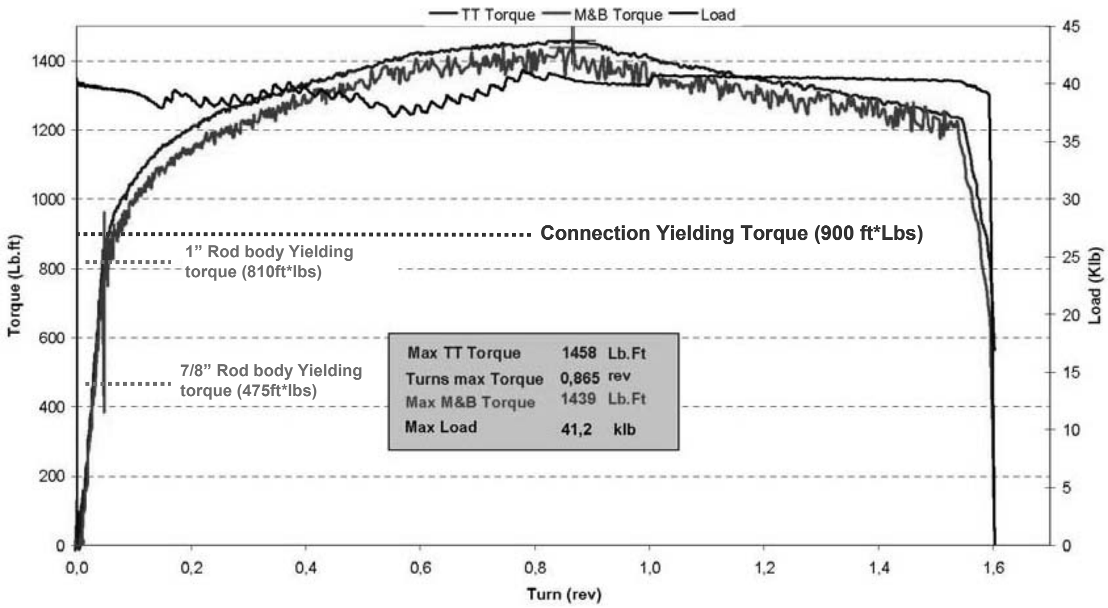

Figure 5 - Combined test graph, tension (40000 lbs) plus torsion to failure D 4142 1" Rod body with 7/8" Premium Connection.

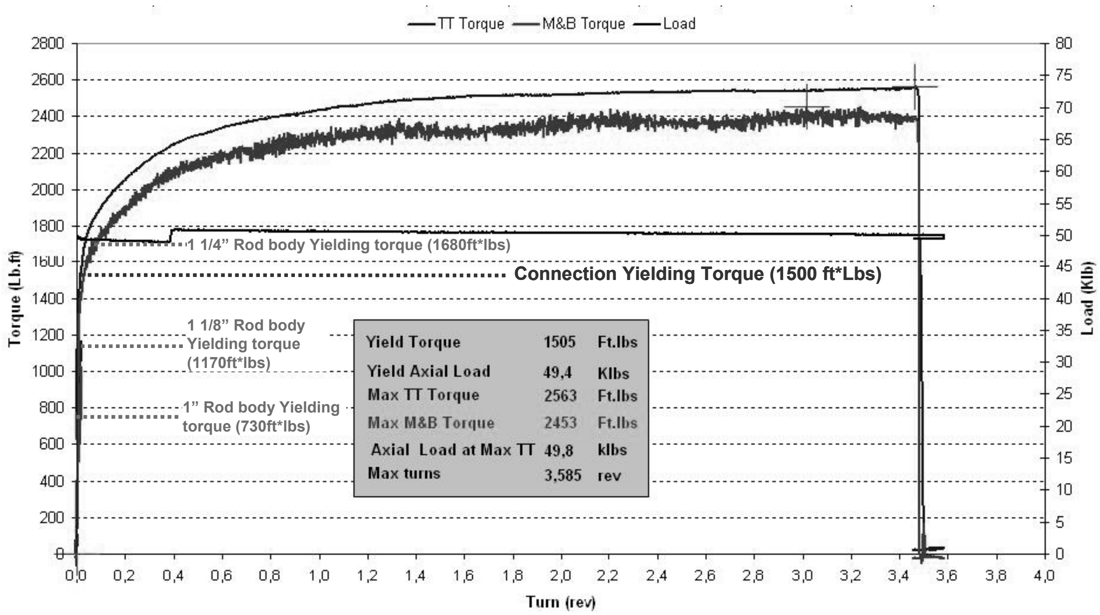

Figure 6 - Combined test graph, tension (50000lbs) plus torsion to failure D 4142 1 1/8" Rod body with 1" Premium Connection