PREDICTING THE USEFUL LIFE OF A SUCKER ROD CONNECTION

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ABSTRACT

Sucker rod pin and coupling failures continue to plague the oil and gas industry and escalate lifting costs. The rod connection is solidly designed and will remain coupled if it is properly treated in the field. Clearly, all paths to the root causes of the premature connection failures lead to field techniques, practices, and to unrecognized and uncontrollable variances. The useful life of a sucker rod is evidently dependent, in part, to how it is handled in the field.

This paper will present datasets gathered from the recently developed Circumferential Displacement Tool ("CDT") to illustrate "the useful life" of the sucker rod connection, ranging from its initial make up to a point where permanent deformation might call for the retirement of the rod and/or connector.

GENERAL DISCUSSION

When running tests or experiments to acquire data, four basic rules must be followed if the results are to be meaningful:

1. Hold constants constant.
2. Control the variables.
3. If the variables cannot be controlled, appreciate how they affect the data.
4. More data points yield more meaningful results.

On the surface, it would appear testing to determine the life of a sucker rod connection should be a fairly easy, straightforward task. One might simply make up rod connections repeatedly, looking for deformations that would indicate the connection will no longer stay together. Repeat many times, get good samplings, average the results, and the answer becomes evident. Remain open minded.

In the shop, the approach works quite well; however, in the field where the rod connection resides and functions every day, the effects of the many field variables must be understood in order to predict the life of a connection. Remember: The ultimate objective of this experiment was to determine the life of a sucker rod connection in a field environment, not in a shop environment.

How the tests were performed:

An entirely new type of rod tong called the Circumferential Displacement Tool was used for all tests. This device is unique in that it can make or break either or both the upper and lower threads of the two elements of the rod connection. This feature is accomplished by gripping the coupling, thus making the upper and lower tightening processes independent of each other. Figure 1 illustrates the mechanical configuration of the CDT.

The CDT also has two independent encoders (upper and lower) that constantly and precisely measure the degree of rotation. The CDT also senses upper and lower torque values and its operational software plots and records the torque-turn relationship of every make or break.

The process of making up both ends of a rod connection is quite simple. To set the CDT up, the operator will be prompted from a pick list and asked for four inputs:

- Manufacturer,
- Size,
- Grade,
- New or re-run.

The panel is intuitive and input is by buttons, not a touch screen. At this point, the machine knows the manufacturer's recommended circumferential displacement ("CD") and is ready to run. From that point on, it is just a matter of the operator exercising one of three levers. The CDT processor then:

- Stops the tightening process when the proper CD has been achieved
- Records the encoder and torque data, and a torque-turn chart is computed/printed.
- Looks for anomalies via curve fitting and pressure ranges, and alerts the operator to run or not run the connection in the hole.

If the CD criteria is met, the curve matches an expected family of curves, and the final make-up pressures are within range, the processes signals a "Go" light and horn. In addition, the torque-turn chart is displayed, although there is really no need to look at the chart.

If any one of the aforementioned criteria is out of range, the processor gives a "No-Go" signal and sound. The operator can look to the screen to see what is out range and why the connection should not be run into the hole. It is his decision to lay the connection down or to run it. Figure 2 represents how the processor computes and displays the information needed for precise make up.

Figure 3 illustrates typical make up and break out torque-turn charts. The reason for charting a make is obvious. The reason for charting the breaks will be explained later in this paper, but clearly much can be learned by observing how a rod connection behaves as it is being unscrewed. The ultimate objective is to identify a defective connection and keep it from going into the wellbore. While coming out of the hole, the computer can often detect a defect in the break.

Caveats:

- A marked difference in upper and lower operating pressures can be noted in figure 3. Pay no attention to the absolute pressures because the lower table has a different mechanical advantage than the upper table. The CDT software addresses those differences.

- The pressures displayed are not to be compared to a conventional set of rod tongs.

DATA AND OBSERVATIONS

Norris generously furnished new rods and couplings for this project and each and every one was methodically destroyed while gathering data. The work was focused on 3/4", 7/8" and 1" rods and couplings, and literally hundreds of connections were analyzed.

In an effort to summarize the data, Figures 4 and 5 best convey the life of a sucker rod connection. Figure 4 is a bar graph illustrating the final CD of 16 straight connections of the same ¾ N-97 rod. The first seven makes ranged within plus or minus 2% of the desired target, regardless of the condition of the rod or coupling. The next four connections (8-11) are the same rod and coupling, but with oil on the faces of the rod and coupling. Even with an oily face, the final achieved CD was within 5% of the target. Connections 12-16 were made with the same rods, but with a new dry coupling and, again, they were well within acceptable ranges of obtaining the final desired CD. Some degree of metal transferring or rod face damage occurred in the final few makes.

Each connection was captured/plotted by the processor and a dial caliper or the familiar Norris card confirmed the actual CD. Figure 4 validates the accuracy of the CDT under varying conditions, but the real story is illustrated in Figure 5, which plots the amount of hydraulic pressure required to obtain the CD. Hydraulic pressure is "standard" for the rig crews. Once they card a connection, they use the same pressure to run a rod string and the pressure is held constant, regardless of the conditions (known or unknown) or variables encountered.

The first connection (Rod 1 Figure 5) is for a new ¾" rod and a new Tee coupling. Initially, it took just over 1,200 psi to bring the rod to CD, but the trend line tells the story of subsequent makes and breaks. As each successive connection is tightened (1-7), the amount of pressure needed to obtain CD increases. Connection 7 needed 1,600 psi to bring it to the proper CD, which represents a 33% increase over the initial make. After connection 7, a detailed visual inspection was made of the rod and coupling; scoring and fretting was evident on the coupling face. Some minor degree of fretting was observed on the rod face, but that was minor compared to the coupling. The CDT software rejected the connection based on a curve fit.

The photos in Figure 6 portray what happened. The upper left photo is the initial make markings for a hand tight SP. The lower left photo is the torque-turn chart of the initial make, which was almost a straight line. The upper right photo is the same coupling and rod, but with an apparent hand tight SP shift. The torque-turn curve in the lower photo has varying slopes during the tightening process, suggesting excessive and uneven frictional forces between the mating surfaces.

Clearly the damage was in the coupling and not the rod after connection 7. The coupling had exceeded the end of its useful life and left unattended to, the roughness of the coupling would start transferring to the rod's mating surface and permanently damaging it. This anomaly begs the question: Why does the coupling face fail before the rod's face?

Most likely the answer to the question lies in the geometry of the coupling. Both API and non-API have a large variance in mating surface face widths, as Art Pena and Arturo De La Cruz reported in their 2002 SWPSC on this subject. Fact is, Pena found a range in widths from .043 to .15 inches and the couplings used during this project had the same variance numbers. That paper is worth re-reading.

Figure 7 is a graphic presentation of the discussion below. The metal yield point of a D rod is 140,000 psi and manufactures normally want to stretch the stress relief portion to 80% of yield. This is accomplished by setting the CD to the prescribed card. The diameter of the stress relief on a 7/8" rod is one inch. Therefore, the cross sectional area of stress relief is:

$$A = \pi R^2 \text{ or } (3.14)(.50)^2 = \underline{.785 \text{ sq. in.}}$$

If the rod is properly tightened to CD, then the force being exerted against the coupling by the rod is calculated as follows:

$$[140{,}000 \text{ psi.}] \text{ X } [80\%] \text{ X } [.785 \text{ in.}^2] \text{ or } 88{,}000 \text{ pounds}$$

If a coupling has a face width of .20", then the mating face surface area is:

$$A = \pi [(R2)^2 - (R1)^2] = 3.14 [.75^2 - .55^2] = .\underline{816 \text{ sq. in.}}$$

If the coupling has a face width of .05", then the mating face surface is:

$$A = \pi [(R2)^2 - (R1)^2] = 3.14 [.75^2 - .70^2] = \underline{.228 \text{ sq. in}}$$

In the case of the wide coupling face of .20", the pressure exerted on the face is:

$$[88{,}000 \text{ pounds}] / [.816 \text{ in.}^2] \text{ or } 107{,}800 \text{ psi....or....77\% of yield.}$$

In the case of the narrow coupling face of .05" the pressure exerted on the face is:

$$[88{,}000 \text{ pounds}] / [.228 \text{ in.}^2] \text{ or } 386{,}000 \text{ psi....or...276\% of yield.}$$

Figure 8 contains photos illustrating how the faces gradually become rough as the surface area is subjected to such high tensile forces.

Figure 9 illustrates how the CDT processor captures the breaks on the rods. The chart on the left is normal and the chart on the right is a damaged face. Normally, when a sucker rod is untightened, it will "snap" free (left chart). If the face is damaged, the snapping action is gone as shown in the right chart.

The data from the test suggest the coupling might be a much larger contributor to premature failures than previously imagined. Defective faces may lead to:

- Increased chances of leakage.
- A false or early "hand tight" shoulder point ("SP") detection. (If the rod is carded and the perceived SP is early due to a burr on the face, the final CD will be too loose.)
- Abnormal hydraulic pressure requirements needed to properly tighten the rod.

At first glance, one would assume that a good crew could visually catch a damaged coupling mating surface: However that is not true in half the cases. Consider what is happening on a rig while running or pulling rods. While resting on the rod elevators, if the coupling is looking up, a visual inspection is quite simple. On the other hand, if the pin is looking up and the coupling is looking down on the engaging member, the crew does not and cannot looks under the rod to observe its face.

Figure 10 illustrates "SP Walk" as a rod and coupling is made up multiple times. This chart only displays the first ten degrees of rotation during the makeup process. As expected, from the initial (first time) make until the coupling is burnished in, a shift of from 4 to 5 degrees is visible. (This is why some rod manufactures have cards with new or re-run options.) If the rod is inadvertently over tightened, the walk or shift will be more pronounced, will accelerate fretting, and shorten the life of both the rod and coupling. In Figure 10, the curve marked as having a burr on the coupling face. This is apparent because the applied hydraulic pressure immediately jumps to two times threshold before it settles to a normal slope. Rather than sensing normal frictional forces as a resistance to tightening, the CDT must apply additional forces to "bury" the burr back into one of the faces, either the coupling or the rod itself. In any event, irreparable damage or permanent deformation has occurred to at least one component of the connection. Via curve fitting and software, damaged mating surfaces can be detected.

How much of a SP walk is too much before deformation has taken its toll on a coupling face? If a 7/8" SMSH coupling has an outside diameter of 1.625 inches, then the circumference is:

C = [π] X [1.625"] or 5.1"

For argument's sake: Define abnormal as being the point where excessive deformation has taken place or where metal started to transfer from the coupling to the rod face. If a 4 to 6 degrees SP shift is normal or still usable, and any amount past that point is abnormal, then:

A normal shift becomes: [5.1"] X [6/360] or .08 inch around the circumference.

The abnormal point or time to replace the coupling is "anytime the SP has shifted past .08 inches."

How much metal has been deformed or compressed during the process? A sucker rod pin has 8 threads per inch which means: As the rod is screwed into the coupling, the coupling and rod will come together at a rate of 1/8 of an inch per complete turn. If the acceptable deformation numbers from the above are accurate, then: The coupling face is still in the elastic region as long as it has not compressed past [6/360] X [.125"] or .002 of an inch on each end.

WET FACES

Going back to Figure 5, connections 8 through 11 were made up with oil on the mating surfaces. As expected, due to a friction reducer being on the surface, the final pressure needed to obtain the proper CD is less than that of a dry face connection. This reduced force requirement is as expected and manufactures mandate a dry connection as friction is used to hold the connection tight.

Figure 11 is a chart of the 16 make pressures, as well as the respective break pressures. The trend of the break pressures is an exact mirror image of the make pressures. From Figure 11, it can be concluded that:

- A wet face connection takes less force to back off than a dry face connection.
- A wet face connection would therefore have greater tendency to loosen in use.
- While pulling out of the hole, trending the break pressures might divulge areas of rod slap or buckling.

Having a wet face does, however, reduce the tendency of fretting and both the rod and coupling faces last longer.

WIDE VERSES NARROW COUPLINGS

Art Pena's 2002 paper reported running several strings of rods using wide faced couplings and he reported that each run required more tong pressure to achieve the CD. Using the CDT, tests were conducted making up the same rods but using both wide face and narrow face couplings. The test results are shown in Figure 12. Clearly it may take up to 40% more pressure to properly tighten a wide faced coupling than it does a coupling with a narrow face. This leads to the question: How can a rig crew compensate for this phenomenon?

THREAD DAMAGE OR FACE DAMAGE

While conducting experiments over hundreds of connections, the CDT was always set to achieve the exact CD. As mentioned before, each connection was measured to visually confirm what the computer had done. In addition, a Norris GO-NO-GO test was performed periodically to insure the threads were not being damaged. As a whole damage occurred in the mating surfaces first and never in the threads. This rule held true until the connection was intentionally over-tightened.

Figure 13 illustrates apparent thread damage occurring due to over tightening. Actually, during the over make process, damage was being inflected to the mating surface at the same time the threads were being overstressed, as that could not be avoided. The blue curve is an early make, still passing the GO-NO-GO make. It shows a clear SP and the slope is normal until the connection goes past CD where the slope takes another bend indicating yielding is taking place. The red curve still passes the GO-NO-GO, test but it has a marked different slope, possibly due to the damaged threads being burnished in. The green curve is the final make on this rod coupling combination, as the rod pin failed the GO-NO-GO test. The coupling passed the thread GO-NO-GO test, but the face was obviously damaged beyond use. The following can be concluded from this portion of the tests:

- Rod pin thread damage will occur when the connection is over tightened.
- The thread in a rod pin will last a long time if properly treated.

There was more to be learned from this experiment. Figure 14 is two photographs of the GO-NO-GO test that failed as exhibited in figure 13.

- In the upper photograph, lower rod, a GO-NO-GO test was performed on the damaged 7/8" rod and as shown, the threads were damaged. The rod failed the test. In the same photo, just above the damaged rod, a new rod and coupling are shown.

- The lower photograph reveals a different story if you use a new coupling for a gage. The upper rod is the GO-NO-GO on a new rod -- the lower rod in the lower photograph is the damaged rod with a new coupling screwed up all the way to the SP.

Conclusion: A GO-NO-GO gage will detect pending thread damage. A new coupling may not.

The only thread damage observed while gathering data for this project occurred when a connection was deliberately over tightened. In an attempt to ascertain how many cycles the threads are good for when the rod was not miss-treated, the same rod and coupling were made up to the exact CD and then broken out only to be made up to and exact CD again. Both the threads of the coupling and rod pin passed the GO-NO-GO test after 40 connections. Clearly the mating surfaces were damaged, but the threads showed no signs of deformation.

CONVENTIONAL ROD TONGS

Almost universally, rig crews use conventional rod tongs to pull and run rods. These tongs consist of a hydraulic motor, a gear train, and a rotating table that grips the rod flats and spins up the rods. The suggested published process or technique is: The crew should hand make the first two engaging threads and then engage the tongs to complete the tightening process. The concept is not to damage the first few threads and to not get lubricant on the mating surfaces. Unfortunately, this process is rarely practiced as most crews just "stab" the rod and start the turning process.

Referring back to Figure 11, where a damaged rod was being screwed into a damaged coupling: A conventional set of rod tongs would never see this anomaly and the reason is: The crews adjust a hydraulic by-pass valve or a pressure regulator to the pressure needed to achieve the final tightness. The rig pump is capable of pumping a given amount of fluid, often times up to 40 gallons per minute. The available hydraulic horsepower (a function of pressure times flow rate) is thereby fixed for both the tightening and the final make processes. The tongs will just rotate through any defect or anomaly in the tightening process like nothing is there.

Most often they say they know their tongs and set the stall pressure by placing a wrench in the rotating table, thereby setting the stall pressure to some preconceived value. If they card the rod run, they determine the required pressure for that connection; leave it there, and just run rods. Looking at Figure 11, it takes about 500 to 600 psi to overcome the thread damage and continue on with the tightening. If the operator of conventional rod tongs has the final tightening pressure set above that point, then the tongs are just going to spin right through the damaged threads and no one knows the difference. For the record, most conventional rod tongs operate in the range of 700 to 900 psi depending on the rod size, grade, and the model of tongs (Mark IV or V).

SUMMARY

From the lab coat or shop's prospective, the following conclusions can be made for this project:

- The rod coupling, when made up dry and properly tightened, will survive from 5 to 7 makes before the surface of the coupling becomes too damaged for further use. Re-surfacing should be considered.

- The coupling's threads will long outlive the mating surface.

- The wider the mating surface of the coupling, the tighter the connection. A wider face should reduce the propensity for the connection to become loose due to wellbore conditions and a wider face will not yield as quickly as a narrow face.

- After making over 40 makes on a rod and coupling, no evidence was found to indicate that either pin or coupling threads would yield IF the make-up process is properly done.

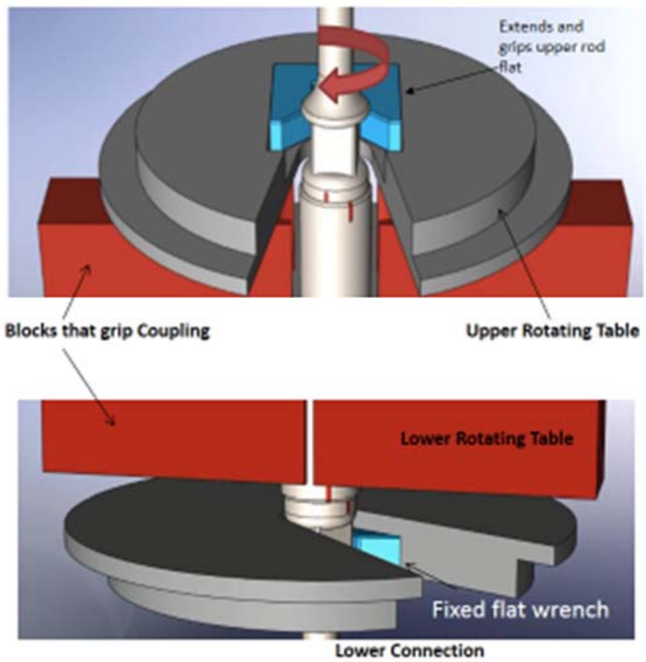
- Over tightening a rod connection will deform the metal: Yield the threads and destroy the mating face quickly.

- If a damaged faced coupling is not replaced, the rod's mating surface will begin to absorb some of that damage and it will shorten the life of the rod.

- Hydraulic pressure cannot be used to precisely control the make up a sucker rod. Pressure will work on one rod for that particular rod-coupling combination for one time. It will not work on a rod string that has variables such as multiple runs and varying coupling face widths.

Circumferential Displacement Tool

1



2

Processor and Data Base

Operation Date	Make-Up Time	CD Goal 35.84 Upper Degrees	0.50 inches Upper PSI
2/5/2014	14:06:03	99.51	364
2/5/2014	14:06:03	100.72	372
2/5/2014	14:06:04	101.86	400
2/5/2014	14:06:04	103	433
2/5/2014	14:06:04	104.14	466
2/5/2014	14:06:04	105.17	487
2/5/2014	14:06:04	106.18	505
2/5/2014	14:06:04	107.22	529
2/5/2014	14:06:04	108.21	542
2/5/2014	14:06:04	109.19	576
2/5/2014	14:06:05	110.26	586
2/5/2014	14:06:05	111.24	610
2/5/2014	14:06:05	112.22	642
2/5/2014	14:06:05	113.14	667
2/5/2014	14:06:05	113.96	682
2/5/2014	14:06:05	114.76	712
2/5/2014	14:06:05	115.62	734
2/5/2014	14:06:06	116.44	760
2/5/2014	14:06:06	117.22	789
2/5/2014	14:06:06	118.04	822
2/5/2014	14:06:06	118.82	850
2/5/2014	14:06:06	119.59	870
2/5/2014	14:06:06	120.3	888
2/5/2014	14:06:06	120.99	911
2/5/2014	14:06:06	121.69	941
2/5/2014	14:06:07	122.34	972
2/5/2014	14:06:07	123.04	1004
2/5/2014	14:06:07	123.66	1020
2/5/2014	14:06:07	124.5	1040
2/5/2014	14:06:07	124.96	1060
2/5/2014	14:06:07	125.69	1080
2/5/2014	14:06:07	126.33	1101
2/5/2014	14:06:07	127.01	1127
2/5/2014	14:06:08	127.65	1164
2/5/2014	14:06:08	128.29	1211
2/5/2014	14:06:08	129.06	1254
2/5/2014	14:06:08	129.78	1295
2/5/2014	14:06:08	130.51	1326
2/5/2014	14:06:08	131.22	1357
2/5/2014	14:06:08	131.88	1385
2/5/2014	14:06:08	132.56	1410
2/5/2014	14:06:09	133.24	1429
2/5/2014	14:06:09	133.89	1446
2/5/2014	14:06:09	134.57	1469
2/5/2014	14:06:09	135.12	1492
2/5/2014	14:06:09	[illegible]	1516
2/5/2014	14:06:09	136.37	1517
2/5/2014	14:06:12	136.47	1033

Upper Shoulder = 100.72

Passed

The processor knows the target based on the operator's input

1. Manufacturer
2. Size
3. Grade
4. New/Re-Run *(Example is a N 90 7/8")*

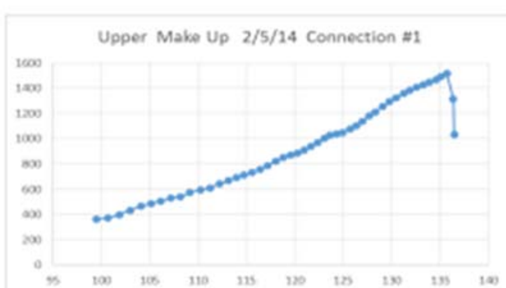
The processor measures and records

1. Degree of rotation
2. Applied Pressure

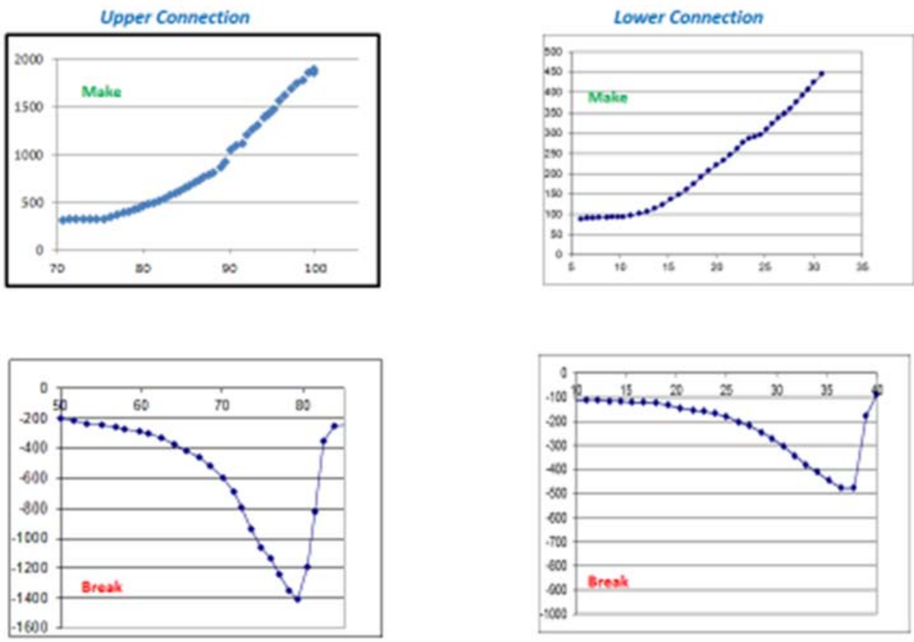
The processor computes the Shoulder Point based on the curve/slope changes.

The Processor stops the rotation when the CD has been achieved
The Processor charts/displays the torque-turn chart and computes a GO-NO GO signal

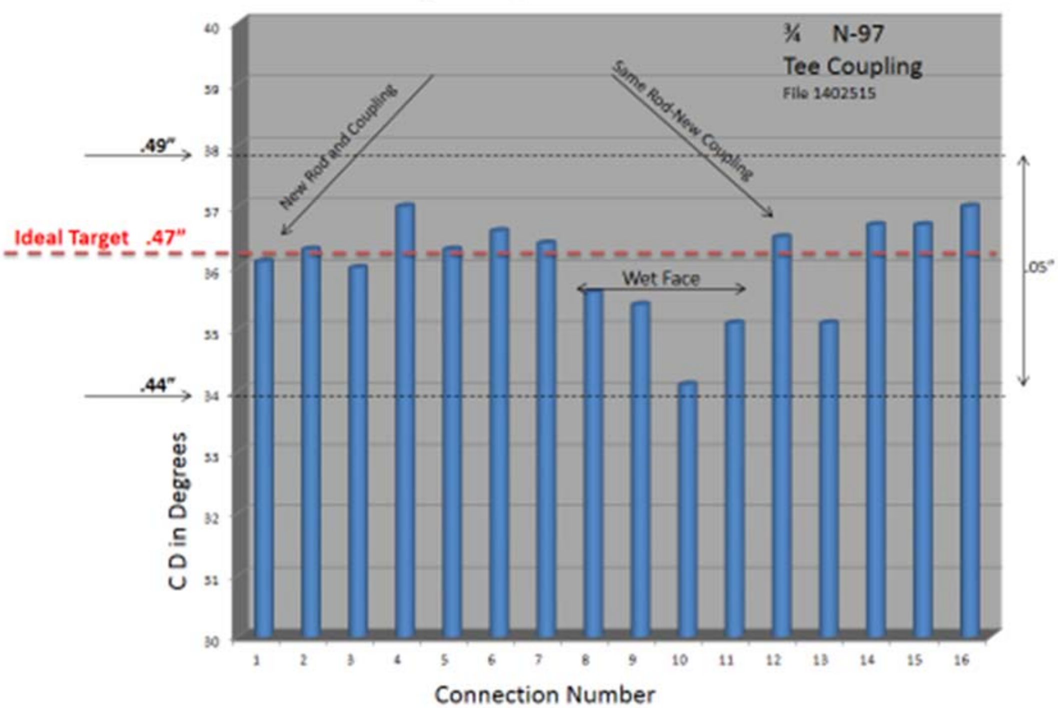
(136.47) – (100.72) = **35.75**



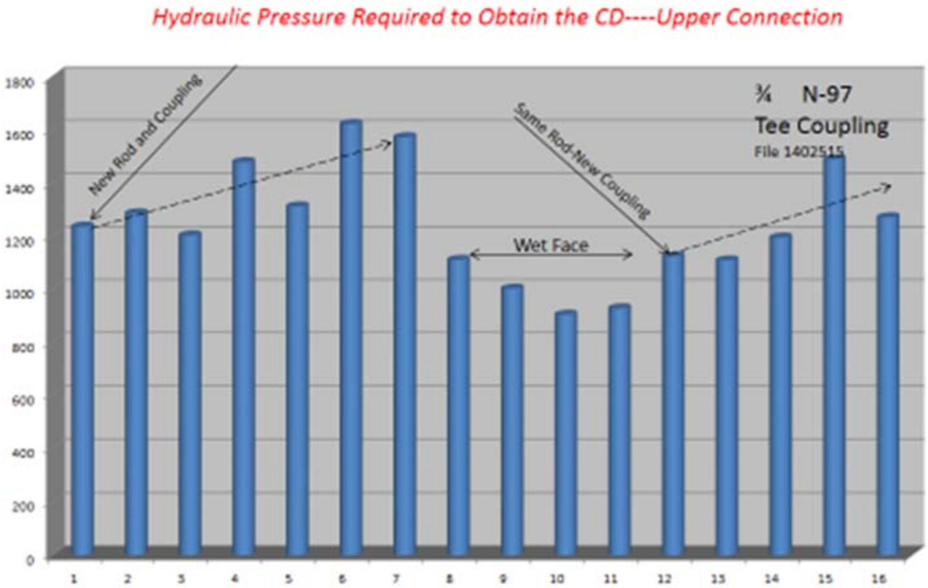
Curve Shapes of Normal Makes and Breaks 3



Achieving the Target CD Under Different Conditions. 4

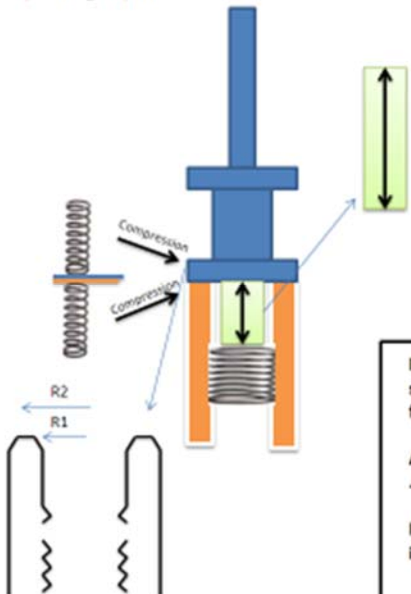


Hydraulic Pressure Required to Obtain the exact CD Upper Connection 5



Shoulder Point Walk and Coupling Fretting 6

Desired **tension** in rod stress relief section mandated as a percentage of yield.



* Face width information from Pena/De

7

The cross sectional area of the stress relief in a 7/8" is

$A = \pi R^2$ or $(3.14)(.50)^2$ = <u>.785 sq. in.</u>

Coupling Mating Surface Area

IF: R2 = .75" and R1 =.60" (Maximum Coupling Width found) *1
The cross sectional area of the coupling mating surface is:

$A = \pi [(R2)^2 - (R1)^2] = 3.14 [.56 - .36] = \underline{.628 \text{ sq. in.}}$

IF: R2 = .75" and R1 =.70" (Minimum Coupling Width found) *2
The cross sectional area of the coupling mating surface is:

$A = \pi [(R2)^2 - (R1)^2] = 3.14 [.56 - .49] = \underline{.220 \text{ sq. in.}}$

If the yield of a D rod is 140,000 psi and the CD is to stress the stress relief to 80% of yield, then: 140K X .80 X .785 in² results in a force of 88,000 pounds be exerted against the mating surfaces.

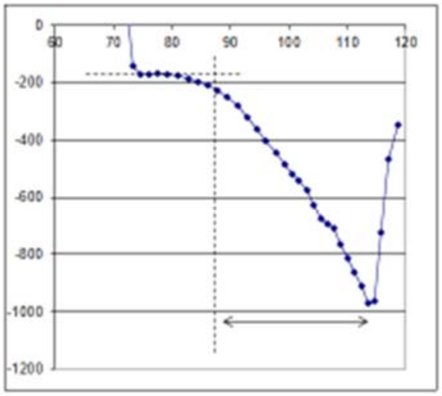
Assume the cross sectional area of the coupling mating surface is .628 in²: 88,000/.628 in² or 140,800 psi or the <u>surface is at yield</u>.

However: If the cross sectional area of the coupling mating surface is .22 in²: 88,000/.22 in² or 400,000 psi.

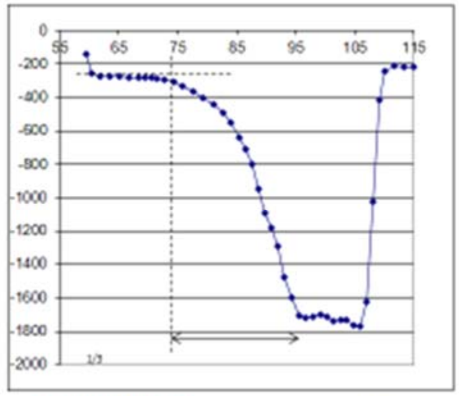
The mating surface is <u>2.8 times yield.</u>

8

Curve Fitting of Breaks

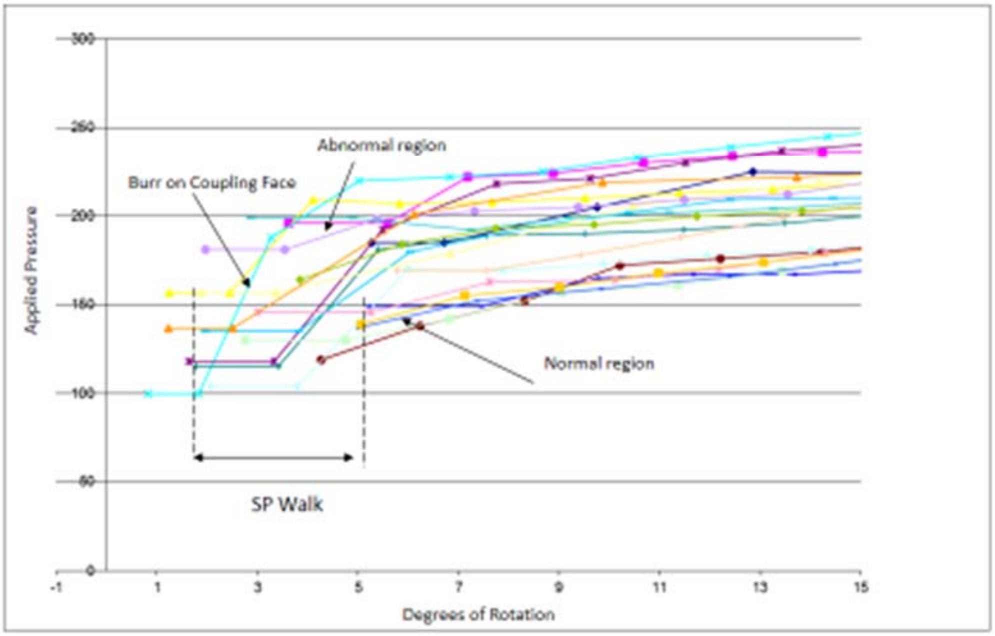


Normal break. Downward Slope begins immediately after reaching peak break out pressure.

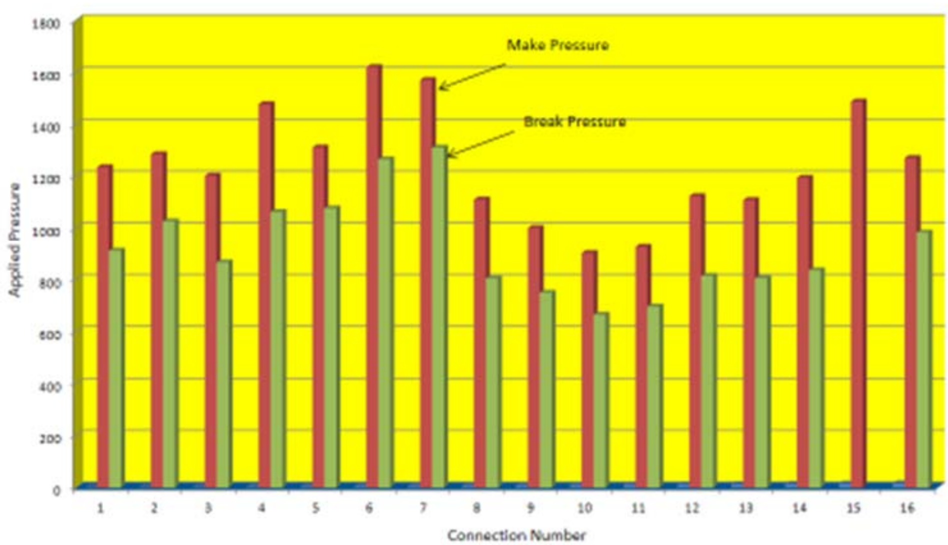


Abnormal break. Took several degrees of rotation before establishing a downward slope.

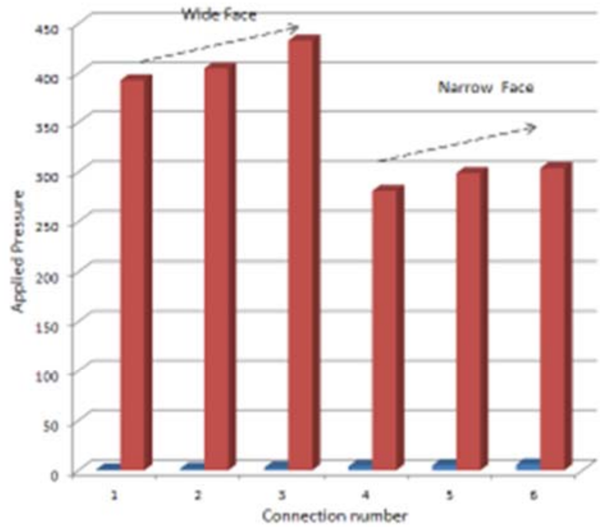
Shoulder Point Shift or Walk Due to Mating Surface Deformation

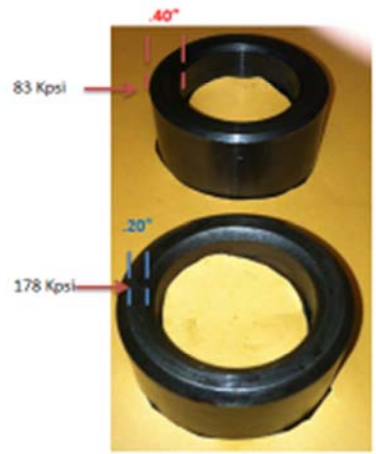


Make Pressure verses Break Pressure



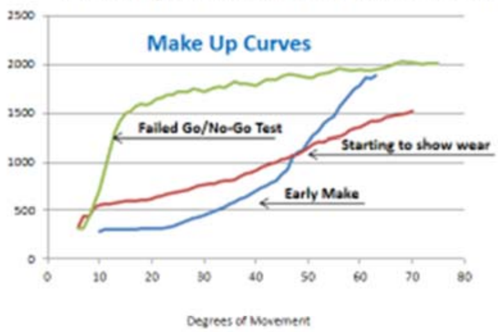
Amount of Pressure Needed to Achieve CD Comparing
Wide Face and Narrow Faced Couplings

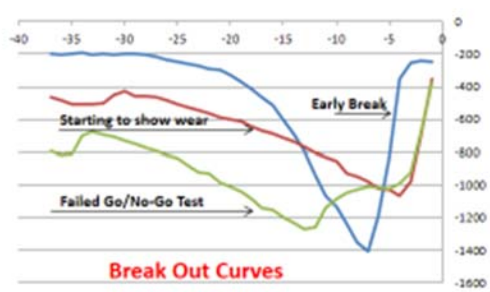




N-97 ¾ Rods
Same rod s used in all six makes

Predicting the useful life of a sucker rod connection using type curves





Data from a
•N-7/8" 97 rod
•API SMSH Coupling

The blue curves illustrate a normal break and make. (Initial)

The red curves illustrate a abnormal but still useable make and break. (passed the Go/No-Go gage test.

The green curves illustrate rod thread damage wherein the threads did not pass the Go/No-Go gage test.

14012412 1 24 N-97 bottom top