CIRCUMFERENTIAL DISPLACEMENT – PARTIAL HISTORY OF THE INDUSTRY PRACTICE

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ABSTRACT

The oil & gas production industry has long used circumferential displacement (CD) for making up sucker rods. This is primarily to assure there is sufficient pre-stress "locked" in the threaded connection to prevent separation and allow the axial loads generated during pumping to be carried by the rod string without connection failures. The CD method also overcomes the problems with using only torque for makeup since torque has been proven to be an inaccurate makeup method mainly due to overcoming the various friction factors. These include: surface finish effects and lubrication effects. This paper provides a partial summary of the original tests conducted by Norris to establish the minimum recommended CD values along with additional testing programs conducted over the past forty years.

INTRODUCTION

During the past few years a few companies have conducted tests on sucker rod connections and the use of CD, but without complete understanding of the prior work that has been conducted and adopted by the industry in API RP 11BR.[1] A possible reason for this is that unless you were a member of the API task group, you did not see the actual tests and results. The only thing remembered was the information that was approved by the industry and adopted in the API standard.

The other part of the problem with not knowing the test results is that Dover- Norris had formally published the various testing programs and their results until now.

Three test programs on CD were conducted over the years. These were in 1968, 1984, and 1989. Additionally, some related tests on the performance of the connections using different CD values and fatiguing the connection in air were conducted in 1989. These tests and their results will be summarized in this paper.

TESTING EQUIPMENT

The connection loading tests were conducted under these various programs using the same equipment. Figure 1 shows a drawing of the rod loading equipment and the measurement of torque loading measuring the applied load on a Dillon 1000 pound dynamometer and knowing the lever arm was 12-inches long. Additionally, the strains obtained from the related CD were measured with Micro Measurements ES-66-067ED-120 with LE option strain gauges. Three gauges were placed at 120^{o} around a sucker rod pin undercut after drilling through the pin upset to run the gauge leads back to the electronic equipment. This assured the threaded connection had 100% integrity and the strain results were not reading hot spot stresses.

The strain measuring equipment consists of three different cabinets from BLH Electronics. These contained the channel input board, the switching and balancing unit and the strain indicator unit. Figure 2 shows a picture of the connection loading test bench along with two of the measuring cabinets. Figure 3 shows a close-up of a loaded connection with the strain gauges leads coming through the drilled hole in the forging upset.

1968 TEST PROGRAM

The original CD testing was conducted and provided to an API task group that was charged in investigating sucker rod connection make-up. The task group consisted of:

- B. R. Bruton (Chairman)
- Lee Current (Oilwell)
- Dean Hermanson (Continental-Emsco)
- Robert A. Morris (Dover – Norris)

– C. R. Neilson (National Supply)

The API Spec 11B sucker rod C, K and D grades were tested using ½", 5/8", 7/8", 1" and 1-1/8" rod diameters. The strain gauge results were converted to stress and typical graphs for the various size rods were provided. These are shown in Figure 4. The accepted results provided a pin pre-stress of 40,000 to 45,000 p.s.i. for C and K grade rods. Table I provides the summary table for remade C and K grade rods. The results showed that to provide the similar stress levels for D grade rods, an extra 2/32" of CD was required for new rods; but, not required thereafter. Additionally, it was found that to provide consistent pre-stress for C and K grade rods, the connection for new rods should be fully made up, unmade (broken), and then remade using the following minimum values shown in Table I..

The task group accepted the work and test results on June 10, 1968. These results were later successfully balloted, accepted by the industry and published in API RP 11BR.

1984 TEST PROGRAM

The CD program at Norris was continued in 1984 consisted of three main objectives. These were to investigate re-run make-up effects, face contact effects, and lubrication effects.

Figure 5 shows the rerun test results that were verified the CD values for C grade rods to obtain approximately 40,000 p.s.i.. Figure 6 shows the graphical results for D grade rods and the resulting approximate 68,000 p.s.i. pin pre-stress for various diameter rods. Figure 7 shows the results of the coupling face tests with full sized and narrow face with pin lubricated. Figure 8 shows the results of the coupling face using full sized and slim hole couplings but with the pin and coupling face lubricated. These results showed the need to increase torque/CD for narrow faced couplings to obtain the similar results as full sized, wider faced API T class couplings. The difference in pin pre-stress for slim hole versus full sized couplings did not show much difference but this may be due to the both the pin and face were lubricated. The effects of lubricating the pin and face versus only the pin threads showed that the required torque/CD is greatly reduced. However, concern was expressed if the pin pre-stress would be retained since the contact area was insufficiently "burnished" or rubbed together to obtain a bond to lock in the stresses.

These results were provided to API and appropriate changes were approved and made in API RP 11BR for proper lubrication of only the pin after sufficient cleaning of the pin threads along with the required CD for D grade rods.

1989 TEST PROGRAM

The CD test program for 1989 at Norris consisted of testing the special, non-API extra high strength grade (Norris 97) rod connection versus similar diameters of API grades C & D rods and the rerun CD effects on pin pre-stress. Additional tests were conducted at an independent test lab to determine the affects of connection pre-stress on the air fatigue performance of the rods. The rods were loaded in a range of 20,000 to 40,000 p.s.i. with the CD values of 50%, 100% and 150% from the minimum recommendations for the 7/8" diameter rod used in the tests.

Figure 9 shows the graphical results for the CD of the various rod diameters versus rod grade and the resulting pre-stress. This shows the required CD for different diameters resulted in a pre-stress of approximately 40,000 to 45,000 p.s.i. for the C grade, approximately 67,000 to 69,000 p.s.i. for D grade, and 77,000 to 79,000 p.s.i. for the Norris 97 grade.

Figure 10 shows the air fatigue test results. Note if less than the minimum pre-stress was applied, then the fatigue life was the shortest and failures occurred in both the threads 70% of the time and elsewhere 30% of the time. If the minimum recommended pre-stress was used fatigue life was longer and no failures occurred in the threads. However, if 150% CD was used, then longer fatigue life was obtained and again with no failures in the threads.

CONCLUSIONS & RECOMMENDATIONS

1. Many tests have been conducted over the past 40 years to investigate sucker rod connection make-up.
2. Minimum values have been determined to provide pin pre-stress of approximately 40 ksi for Grade C; 68 ksi for Grade D and 88 ksi for HS rods.
3. However, since yield strength of the actual rod materials are typically >10% more than minimum specified, more CD would be required to obtain adequate make-up
4. This added CD is normally accounted for in the manufacturers CD card versus just using the minimum values in API RP 11BR

5. It is recommended to use manufacturer's CD card for their specific rod grades and diameters.
6. If applied stresses are greater than pin pre-stress, connection separation will occur.
7. These loads may not be recorded by dynamometer investigation, but impact loads from pounding fluid (liquid and/or gas), tagging bottom, over-pumping the well, etc., greatly magnifies actual loads..
8. The proof of downhole separation is in the connection; since no liquids were pumped into coupling when made up, if liquid pours out when disconnected the connection lost pre-stress and separated downhole.
9. The condition of thread form is important to assure applied make-up forces are evenly distributed.
10. Lubrication of pin only assures adequate make-up and contact face burnishing to help keep pre-stress applied.
11. Slim-hole couplings may not show much difference than full sized couplings; but, pin/face lubrication may have affected the results.
12. Most manufacturers have not accounted for the face contact area in their CD recommendations, especially if a narrow face is applied to the coupling.
13. Other testing on connection make-up showed the improvement in fatigue life; but, in the field, these improvements may still be lost depending on operating practices (pounding fluids, tagging bottom, over-pumping the well, etc.)
14. Many of the parameters and resulting reasons why threaded connections fail are analogous to other threaded components
15. The main reasons for failures include: skill of operator making connection, applied load excursions, vibration/ buckling, thermal effects, and in-service failures (failures cause other failures especially if all connections are not remade).
16. It is recommended that if a rod connection has occurred downhole, the condition causing the failure probably loosing other connections. Thus, when running rods back into the well, all connections should be broken and remade to proper CD values.

REFERENCES

1. API RP 11BR, "Recommended Practice for Care and Handling of Sucker Rods," API, Washington D.C., April, 2008.
2. API Spec 11B, "Specification for Sucker Rods," API, Washington D.C., 26th ed., Jan, 1998.

Table I
Recommended CD for Rerun of API C & K Grade Sucker Rods

Rod Size (in.)	1/2	5/8	3/4	7/8	1	1-1/8
Min. CD (in.)	4/32	6/32	7/32	9/32	11/32	16/32

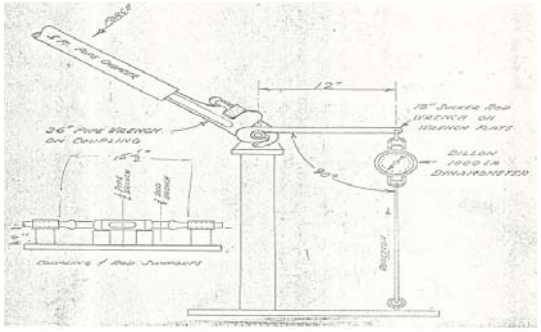

Figure 1 - Drawing showing CD test frame.

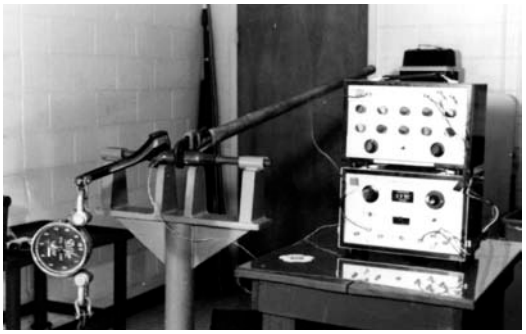

Figure 2 - Photo of test frame and the BLH cabinets.

Figure 3 - Connection showing gauge leads.

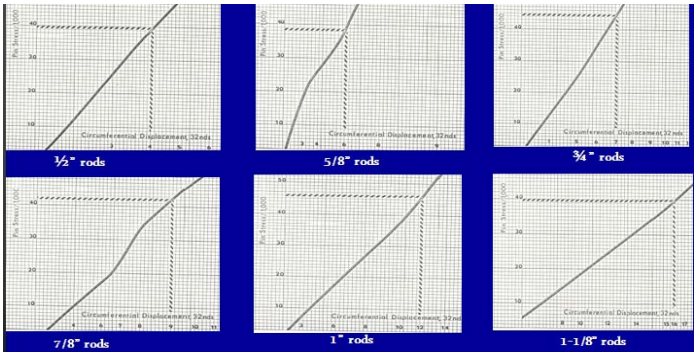

Figure 4 - Pre-stress results for C & K reruns for various diameters.

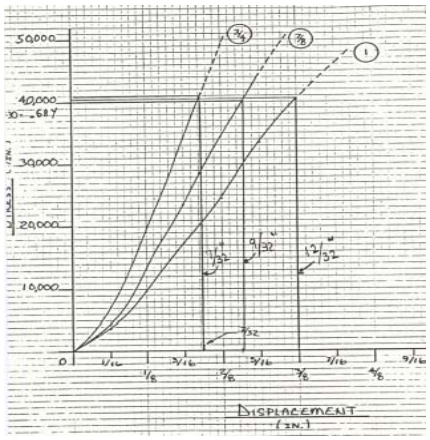

Figure 5 - CD verification for C grade ~ 40 k.s.i. pre-stress.

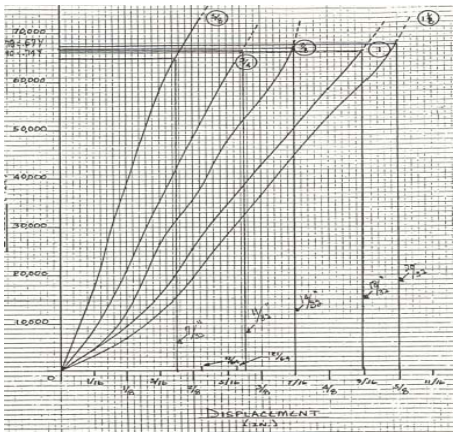

Figure 6 - Rerun grade D for ~68 k.s.i pre-stress.

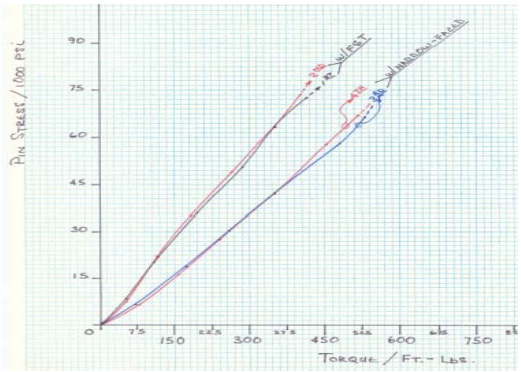

Figure 7 – Pre-stress effects on full face (left) vs. narrow face with pin only lubricated.

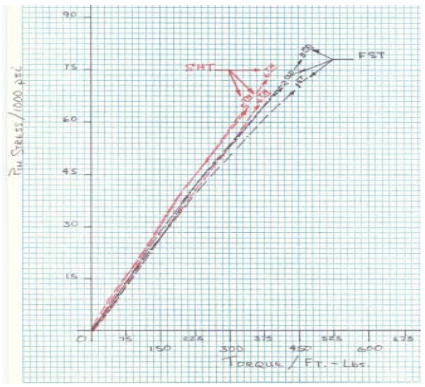

Figure 8 – Pre-stress effect on slim hole (left) vs. full sized coupling with pin and face lubricated.

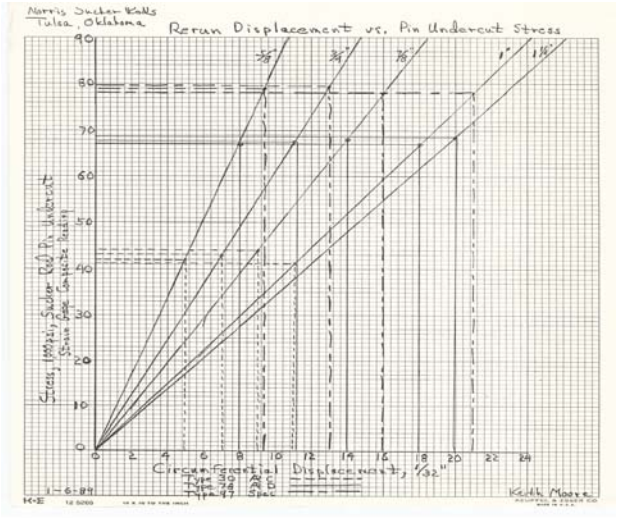

Figure 9 - Comparison of CD, pre-stress for C, D, & 97 rods.

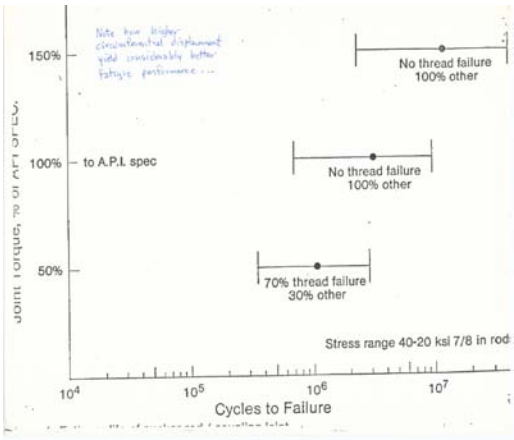

Figure 10 - Air fatigue effects of 50%, 100% & 150% CD.