API 11BR REVISIONS ON SUCKER ROD MAKEUP

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ABSTRACT
The successful application of threaded and coupled rods (e.g., sucker rods, drive strings, etc.) to provide power to lift downhole fluids is critically dependent on using proper makeup procedures. This is applicable whether the pump is a reciprocating, positive displacement pump or a rotary driven, progressing cavity pump. Torque by itself has long been discredited with being able to provide consistent pin preload stress in threaded connections due to a variety of factors related not only to the setup procedures but also due to the equipment that is used to provide energy to the power tongs.

Both test data and theoretical calculations confirm circumferential movement of the threaded connection beyond the hand-tight position provides an accurate and repeatable means to measure and define pin preload stress values. This paper will review various parameters that affect pin preload stress and provide a discussion of changes in the revision of API 11BR as well as newly developed draft recommendations for progressing cavity pump (PCP) systems.

INTRODUCTION
In reciprocating rod lift, the sucker rod connection is affected by tensile loads that try to pull the connection apart. The tensile loads are roughly parallel to the axis of the rod body and try to separate the bearing surfaces of the threaded connection (i.e., tries to separate the pin shoulder and coupling face). The tightening of the coupling, past the hand-tight position, preloads and elongates the pin, similar to a "spring", and produces a compressive stress or a "clamping force" on the bearing surfaces; the compressive stress is approximately equal to the pin preload stress. (Figure 1)

Any additional tensile load applied to the pin preload stress, no matter how small, will partially relieve the pin preload; which reduces the clamping force introduced into the bearing surfaces (Figure 2 – note the loss of the "clamping force" with the addition of 40 ksi tensile load to the existing pin preload stress. However, it should be noted, the 7/8-inch API Grade C Sucker Rod is at +150% of allowable stress when designing with the Modified Goodman Diagram (MGD) and an additional 40 ksi load is applied to the pin preload stress)[1]. The endurance of the threaded connection depends on how tightly the bearing surfaces "clamp" and how long the pin can maintain its preload stress.

On the other hand, the state of stress for threaded connections in reciprocating lift is different from the state of stress for progressing cavity pump systems. Albeit used in PCP systems, the sucker rod was designed and manufactured for reciprocating rod lift systems. Specifically, API 11B, the requirements and guidelines for the design of sucker rods, does not address principle stresses associated with PCP systems. Current revisions to both API 11B and 11BR will not address PCP applications. Industry need for this application is the motivation for the current task group attempting to write an ISO Standard for "drive strings" capable of handling the principle stresses encountered with PCP systems. ISO 15136-3, Progressing Cavity Pump Systems for Artificial Lift, "Part 3 – Drive Strings", and coupled drive strings in PCP systems will be discussed toward end of this paper.

PRELOAD STRESS

For optimum performance, it is imperative that all connections in the rod string be made-up to a given preload stress value in order to prevent separation of the bearing surfaces (i.e., pin shoulder and coupling face) during the pumping cycle. If the pin preload stress is greater than the applied load, no failure should occur.

Parameters that Affect Pin Preload Stress Values

There are many inherent variables which affect threaded connection makeup. These variables include, but are not limited to:

- Grade and size of the rod
- Dimensions, tolerances, and surface finish of the bearing surfaces and threads
- Cleanliness of the pin and coupling threads
- Selection, type, condition and application of a qualified thread lubricant
- Condition of the bearing surfaces
- Thermal affects
- Knowledge and skill of well servicing crews
- Operating characteristics, mechanical condition, and rated capacity of the power tong equipment and related hydraulic system
- Integrity of the threaded connection (e.g., the number of times the connection has been made-up and broken apart
- Optimum pin preload stress values
- Operating conditions (e.g., overloads, fluid pound, friction effects, vibration, contact wear, rod buckling tendencies, etc.)
- In service failure (i.e., failure can lead to more failures if the root cause has not been correctly identified and remedied)

Torque-Based Makeup with Power Tongs

Engine RPM is critical to the hydraulic power fluid flow rate. This affects pressure and associated rotational speed of the power tongs. The engine RPM's should be uniform (consistent and repeatable) throughout makeup. Figures 3 and 4 are examples of monitoring hydraulic fluid temperatures versus time to exemplify the reason for stabilizing operating temperatures for power tongs. Monitoring this temperature is important because as the temperature of the hydraulic fluid increases, the amount of torque decreases and subsequent pin preload stress decreases (i.e., the service rig's hydraulic system becomes less efficient as the hydraulic power fluid temperature increases).

In addition, hydraulic systems on all service rigs use a spring type pressure relief valve and, by adjusting tension on the spring, the rig operator can set the desired pressure for the power tongs to stall. Increasing tension on the spring raises the pressure of the hydraulic system which results in higher pressures before the power tongs stall. However, as the temperature of the hydraulic power fluid increases, heat from the fluid is dissipated throughout the hydraulic pump. As the temperature of the hydraulic pump increases, the spring tension decreases and the relief valve will open at lower pressures. This results in lower CD values and related connection pin preload stress.[2]

As a result of these variations, an indication of applied torque by only measuring the service rig's hydraulic pressure has long proven to be inaccurate and is not a viable means of consistently achieving the minimum pin preload stress values required for sucker rod connections.

Torque-Measuring Methods

NASA Reference Publication 1228, "Fastener Design Manual", states "A number of torque-measuring methods exist, starting with the operator's feel and ending with installing strain gauges on the pin. The accuracy in determining the applied torque value is cost dependent. Tables 1 and 2 are by two different "experts" and their numbers vary. However, they both show the same trends of cost versus torque accuracy."[3]

PRELOAD STRESS VALUE DETERMINATION

There are a number of methods that are acceptable to determine optimum preload stress values for a threaded connection including, but not limited to:

- Measuring pin stretch or elongation.
- Ultrasonic velocity.
- Torque turns and torque displacement.
- Strain gauge measurement of the actual or applied stress value.

However, these methods are not practical for the determination of sucker rod preload stress values in the field. One method for determining optimum preload stress values for a threaded connection in the field was developed in the 1960's for sucker rods.[4] This method correlates actual strain gauge readings in the laboratory versus the applied torsional load during makeup and the resulting circumferential movement of the coupling to provide the required connection preload stress value. This method is known as circumferential displacement (CD).

Circumferential Displacement (CD)

CD is the distance measured, after makeup from the hand-tight position, between the displaced parts of a vertical line scribed or drawn across the external surfaces of both ends of the coupling and both pin shoulders. Manufacturers should provide users with the optimum CD values for their products. If the CD values are not available or provided by the manufacturer, Table 3 for new CD values or Table 4 for rerun CD values may be used.

CD Method

The following procedure describes the method to achieve optimum pin preload stress using CD.

1) Select the appropriate coupling for the type and size of pin thread (e.g., sucker rod, polished rod or sinker bar pin thread).

2) Clean and assess the condition of both pins and both coupling ends with particular care in the assessment of the threads and bearing surfaces.

3) Apply a small quantity of a qualified thread lubricant, per manufacturer's recommendations, to one side of the first three lead or starting threads of the pin – only (Figure 5). It is extremely important to properly lubricate the pin threads and maintain dry bearing surfaces for correct makeup (i.e., the pin shoulders and coupling faces need to be in good condition, clean, dry and without lubricant).

4) Tighten the coupling on the pin to the hand-tight position. The hand-tight position is determined to be the condition after making up the coupling to the pin thread by hand so there should be no gap exceeding 0.002 inches maximum for 360 degrees around the entire bearing surfaces of the pin shoulder and coupling face. If the gap is greater than 0.002 inches maximum at any point around the circumference of the connection, replace the coupling first and retest the connection in the hand-tight position. If the makeup of the second coupling fails, segregate the rod for subsequent assessment by qualified personnel and use a replacement rod and retest the connection from the hand-tight position.

5) Scribe, mark or draw a vertical line across both pin shoulders and the corresponding coupling ends (Figure 6).

6) The minimum pin preload stress is obtained by tightening the connection with rod wrenches (manual CD) or power tongs (dynamic CD) to the recommended CD value for the grade, size and condition of threaded connection, as required by the manufacturer. If CD values are not available or provided by the manufacturer, Table 3 for new CD values or Table 4 for rerun CD values may be used.

7) Verify that both ends of the connection meet the minimum required CD between the scribed vertical lines using the edge of the mark on the pin shoulder and the corresponding edge of the mark on the coupling for both pin shoulders and corresponding coupling ends.

COMPUTERIZED ROD TONGS

Newer methods for determining adequate pin preload stress values based on torque turns or torque displacement are available. These newer methods utilize computerized rod tongs to measure applied torque and either the number of torque turns or the final circumferential displacement of the coupling to the pin shoulder. These methods provide similar accuracies for the measurement of pin preload stress as the CD method and may be especially useful for larger diameter, high strength and specialty rods where current CD values may not be provided by the manufacturer for the product application (e.g., 1 1/4 inch and 1 1/2 inch coupled drive strings). However, it should be noted, computerized rod tongs are not yet widely used in the industry due to their limited availability and may be thought of as cost preventative if one doesn't consider failures as part of the total cost to using these specialty tools.

THREAD LUBRICANT SELECTION

As part of the new revision of 11BR, the task group has defined a test procedure to determine qualified thread lubricants for threaded connection makeup. Thread lubricants shall be selected and qualified, using a new sucker rod pin end and a new sucker rod coupling, and based on the qualification procedure shown below.

Qualification Procedure

1) Select and apply a thread lubricant to the pin threads, per manufacturer's recommendation.

2) Thread lubricants shall have sufficient viscosity to remain on and protect the threads at ambient temperatures from -40 °F (-40 °C) to 122 °F (50 °C).

3) Tighten the coupling on the pin to the hand-tight position.

4) Apply the appropriate CD value for the grade and size of sucker rod.

5) Completely disassemble the connection.

6) Inspect the pin and coupling threads for visual damage without removing the remaining thread lubricant.

7) Without applying new or additional thread lubricant, repeat steps 3, 4, 5 and 6 for a total of 10 complete cycles.

8) Completely disassemble the connection.

9) Clean and inspect the pin and coupling threads for visible damage or thread galling.

10) Clean and inspect the bearing surfaces for visible damage.

Qualified Thread Lubricants

A qualified thread lubricant is one which results in no visible damage or galling of either the pin and coupling thread form or the bearing surfaces during the 10 complete cycles required in the qualification procedure.

AMERICAN PETROLEUM INSTITUTE (API)

API formed in 1919 as a national trade association to support the U.S. Oil and natural gas industry through legislative and regulatory advocacy and standards development. The API Standards Department was formed in 1923, and the first API standard was published in 1924 covering pipe sizes, threads and couplings. API is an ANSI-accredited Standards Developing Organization (SDO) and these standards, recommended practices, equipment specifications, technical documents, reports, and studies are published to facilitate the broad availability of proven, sound engineering and operating practices worldwide.

API's Standards Committees are made up of subcommittees and task groups consisting of industry experts who develop API standards. The subcommittees and task groups identify the need, then develop, approve and revise standards and other technical publications. The standards-writing subcommittees and task groups are open to representatives of groups that are materially affected by the standards. These include oil and gas companies, manufacturers and suppliers, contractors and consultants, and representatives of government agencies and academia. API encourages representatives of companies and organizations involved in the use or manufacture of oilfield equipment in any country to actively participate in the API standardization program[5].

SC11 – Subcommittee on Field Operating Equipment

SC11 tasked with developing, approving, revising and maintaining standard and other technical publications associated with pumps, sucker rods, pumping units and submersible pumps. Currently, approximately six standards, fourteen recommended practices, two technical reports, and two bulletins fall under the jurisdiction of SC11. Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years and several of those documents are either in revision or out for ballot. In particular, and for the purpose of this paper, we will focus our discussion around both API 11BR and 11B.

API 11BR – RECOMMENDED PRACTICE FOR THE CARE AND HANDLING OF SUCKER RODS

API 11BR covers the care and handling of steel sucker rods, including guidelines on selection, allowable stress, proper connection makeup, corrosion control and used rod inspection. The current edition of API 11BR was published in 2008 as API Recommended Practice 11BR, Ninth Edition, August 2008. This recommended practice is in revision.

Changes

Changes include:

- Format
- Scope
- Additional products
- Expanded annexes
- New annexes

Format

The revision uses separate annexes for products, makeup of shouldered connections utilizing circumferential displacement, corrosion control, inspection facilities, calibration and calibration requirements, etc.

Scope

The scope will be expanded to include all products currently listed in API 11B plus the inclusion of high strength sucker rods.

Additional Products

All products currently listed in API 11B and high strength sucker rods will be added. Updated and revised CD tables for new and rerun CD using the averages values currently recommended by manufacturers.

Expanded Annexes

Expanded sections include the selection of API steel sucker rods, allowable stress determination utilizing range of stress, makeup of shouldered connections utilizing circumferential displacement, storage and transportation, care and handling, running and pulling of all equipment listed in the document, new and updated color codes for material types, etc.

New Annexes

New sections include thread lubricant selection, minimum requirements for inspection facilities, inspection of products manufactured in accordance with API 11B, non-destructive methods of inspecting new steel sucker rods, fiberglass sucker rods, sinker bars, polished rod and couplings, non-destructive methods of inspecting used steel sucker rods, fiberglass sucker rods, sinker bars, polished rod and couplings, mechanical properties testing of 11B products, etc.

API 11B – SPECIFICATION FOR SUCKER RODS, POLISHED RODS AND LINERS, COUPLINGS, SINKER BARS, POLISHED ROD CLAMPS, STUFFING BOXES, AND PUMPING TEES

API 11B provides the requirements and guidelines for the design of steel sucker rods and pony rods, polished rods, polished rod liners, couplings and sub-couplings, fiber reinforced plastic (FRP) sucker rods, sinker bars, polished rod clamps, stuffing boxes, and pumping tees. The current edition of API 11B was published in 2010 as API Specification 11B, Twenty-Seventh Edition, May 2010. At the time of the last publication, API 11B had undergone a major update and revision from prior editions[6]. However, this standard is again under review by a task group for revision.

Changes

Changes may include:

- Additional products

- Updated color code requirements

Additional Products

High strength sucker rods and material requirements for couplings and polished rods may be added to the current revision.

Updated Color Code Requirements

New color code charts for material requirements, including couplings, polished rods, etc. may be added to the current revision.

ISO 15136-3, PROGRESSING CAVITY PUMP SYSTEMS FOR ARTIFICIAL LIFT, "PART 3 – DRIVE STRINGS"

A drive string is a critical component of the progressing cavity pump (PCP) system required to successfully deliver torque from the surface drivehead to the pump in order to lift produced fluids to the surface. An ISO work group is drafting ISO 15136-3 to provide the requirements for the design, design verification and validation, manufacturing and data control, performance ratings, functional evaluation, handling and storage for drive strings used in PCP systems. The current draft is broken into annexes that include: a) design validation requirements; b) drive string selection and application guidelines; c) coupled drive strings; d) hollow drive strings; e) continuous drive strings; f) drive string and tubing wear guidelines and considerations; g) troubleshooting guide; and h) displacement cards.

Coupled Drive Strings in PCP Systems

Sucker rods are designed and manufactured for reciprocating rod lift. In a contrast to the state of stress encountered in reciprocating rod lift, coupled drive strings must be capable of withstanding axial loads while transmitting constant, yet fluctuating torque to the progressing cavity pump. The coupled drive string transmits torque at the surface to the pump through the "clamping force" between the bearing surfaces of the threaded connections, with minor additional torque capacity provided by the threads. Since the rod string rotates to the right, it is wrongly assumed that a coupled drive string can be left in the hand-tight position and allowed to "makeup" during startup.

When the pump is started, the drive string will torque-up or twist many times at the surface prior to the rotor moving downhole. In addition to the applied torsional load, elastic energy is stored in the coupled drive string. Optimum pin preload stress is critical since the applied torsional load and stored elastic energy can cause incremental makeup if these combined loads to exceed the "clamping force" between the bearing surfaces; which will result in damage to the threaded connection (e.g., shearing of the pin and/or coupling threads). Common causes for incremental makeup include: 1) insufficient pin preload; 2) lubrication between bearing surfaces; and 3) operating conditions.

SUMMARY

- Revisions to API 11BR should greatly benefit the oil and natural gas industry.

- Optimum pin preload stress is required to keep a shouldered, threaded connection together and reduce connection failures.

- Measuring torque to try to obtain the required pin preload stress is accurate to within ±25%.

- Newer computerized methods of measuring applied torque and displacement is accurate to ±1 to 2%.
- Measuring strain is the most accurate but is impractical in the field.
- The extension of laboratory strain gauge measurements to determine circumferential displacement (CD) values has proven accurate and is recommended as the practical method for use in the field.
- ISO 15136-3, Progressing Cavity Pump Systems for Artificial Lift, "Part 3 – Drive Strings", will provide valuable information for users of PCP systems.

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[2]F.M. Newman, "A Discussion of Service Rig Components and Crew Techniques That Affect Proper Assembly of Tubing, Drillpipe and Sucker Rods", Southwester Petroleum Short Course, 2002, Lubbock, Texas.

[3]Richard T. Barrett, Lewis Research Center, Cleveland, Ohio, NASA Reference Publication 1228, "Fastener Design Manual".

[4]Russell Stevens and Norman W. Hein, Jr., "Circumferential Displacement – Partial History of the Industry Practice", Southwestern Petroleum Short Course, 2010, Lubbock, Texas.

[5]Additional information concerning API is available at www.api.org.

[6]Benny J. Williams and Norman W. Hein, Jr., "American Petroleum Institute Specification 11B – What's New and Improved", Southwestern Petroleum Short Course, 2010, Lubbock, Texas.

Table 1 – Industrial Fasteners Institute's Torque-Measuring Method (REF. 3)

Preload Measuring Method	Accuracy (percent)	Relative Cost
Feel (operator's judgment)	± 35	1
Torque Wrench	± 25	1.5
Turn of the Nut	± 15	3
Load-Indicating Washers	± 10	7
Fastener Elongation	± 3 to 5	15
Strain Gauges	± 1	20

Table 2a – Typical Tool Accuracies (REF. 3)

Type of Tool	Element Controlled	Typical Accuracy Range (percent of full scale)
Slug Wrench	Turn	1 Flat
Bar Torque Wrench	Torque Turn	± 3 to 15 1/4 Flat
Impact Wrench	Torque Turn	± 10 to 30 ± 10 to 20°
Hydraulic Wrench	Torque Turn	± 3 to ± 10 ± 5 to 10°
Gearhead Air-Powered Wrench	Torque Turn	± 10 to ± 20 ± 5 to 10°
Mechanical Multiplier	Torque Turn	± 5 to 20 ± 2 to 10°
Worm-Gear Torque Wrench	Torque Turn	± 0.25 to 5 ± 1 to 5°
Digital Torque Wrench	Torque Turn	± 1/4 to 1 1/4 Flat
Ultrasonically-Controlled Wrench	Bolt Elongation	± 1 to 10
Hydraulic Tensioner	Initial Bolt Stretch	± 1 to 5
Computer-Controlled Tensioning	Simultaneous Torque & Turn	± 0.5 to 2

Table 2b – Control Accuracies (REF. 3)

Element Controlled	Preload Accuracy (percent)	To Maximize Accuracy
Torque	± 15 to ± 30	Control bolt, nut, & washer hardness, dimensions, & finish. Have consistent lubricant conditions, quantities, applications, and types.
Turn	± 15 to ± 30	Use consistent snug torque. Control part geometry and finish. Use new sockets and fresh lubes.
Torque & Turn	± 10 to ± 25	Plot torque versus turn and compare to previously derived set of curves. Control bolt hardness, finish, and geometry.
Torque Past Yield	± 3 to ± 10	Use “soft” bolts and tighten well past yield point. Use consistent snugging torque. Control bolt hardness and dimensions.
Bolt Stretch	± 1 to ± 8	Use bolts with flat, parallel ends. Leave transducer engaged during tightening operation. Mount transducer on bolt centerline.

Table 3 – New (First Run) CD Value Measurements
(all dimensions in inches followed by equivalent in mm)

1 Rod Size		2 New Grades C & K CD Values				3 New Grades DC, DA & DS CD Values				4 New Grades HC, HA & HS CD Values			
inch	mm	minimum		maximum		Minimum		maximum		minimum		maximum	
5/8	15.9	13/64	5.2	17/64	6.7	1/4	6.4	5/16	7.9	5/16	7.9	25/64	9.9
3/4	19.1	1/4	6.4	19/64	7.5	19/64	7.5	25/64	9.9	3/8	9.5	15/32	11.9
7/8	22.2	19/64	7.5	23/64	9.1	23/64	9.1	29/64	11.5	7/16	11.1	9/16	14.3
1	25.4	25/64	9.9	29/64	11.5	15/32	11.9	37/64	14.7	9/16	14.3	23/32	18.3
1 1/8	28.6	1/2	12.7	9/16	14.3	37/64	14.7	11/16	17.5	45/64	17.9	13/16	20.6

Table 4 – Rerun CD Value Measurements

(all dimensions in inches followed by equivalent in mm)

1 Rod Size		2 Rerun Grades C & K CD Values				3 Rerun Grades DC, DA & DS CD Values				4 Rerun Grades HC, HA & HS CD Values			
inch	mm	minimum		maximum		Minimum		maximum		minimum		maximum	
5/8	15.9	3/16	4.8	1/4	6.4	13/64	5.2	9/32	7.1	19/64	7.5	25/64	9.9
3/4	19.1	15/64	6.0	9/32	7.1	1/4	6.4	11/32	8.7	23/64	9.1	15/32	11.9
7/8	22.2	9/32	7.1	23/64	9.1	5/16	7.9	7/16	11.1	7/16	11.1	9/16	14.3
1	25.4	3/8	9.5	29/64	11.5	13/32	10.3	35/64	13.9	35/64	13.9	23/32	18.3
1 1/8	28.6	31/64	12.3	9/16	14.3	17/32	13.5	41/64	16.3	11/16	17.5	13/16	20.6

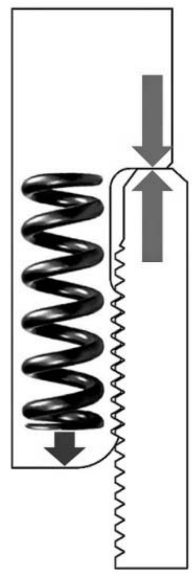

Figure 1 – The tightening of the coupling, past the hand-tight position, preloads and elongates the pin similar to a “spring” while producing a compressive stress or “clamping force” in the bearing surfaces between the pin shoulder and coupling that is approximately equal to the preload or tensile stress in the pin.

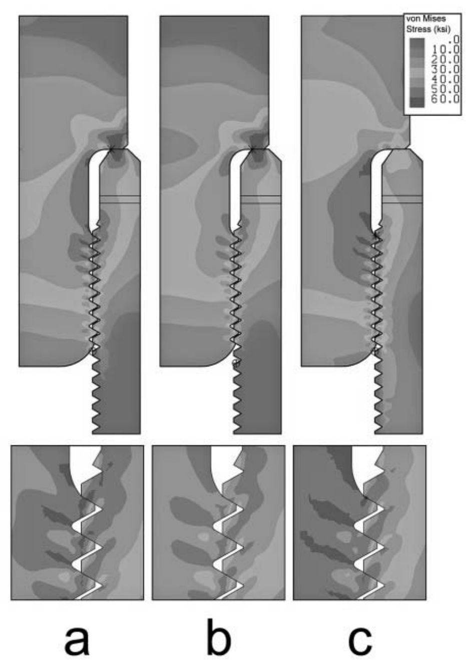

Figure 2 – a) plot of the connection with pin preload stress – only; b) plot of the connection with pin preload stress and -5 ksi compressive stress; and c) plot of the connection with pin preload stress and 40 ksi tensile load. (REF. 1)

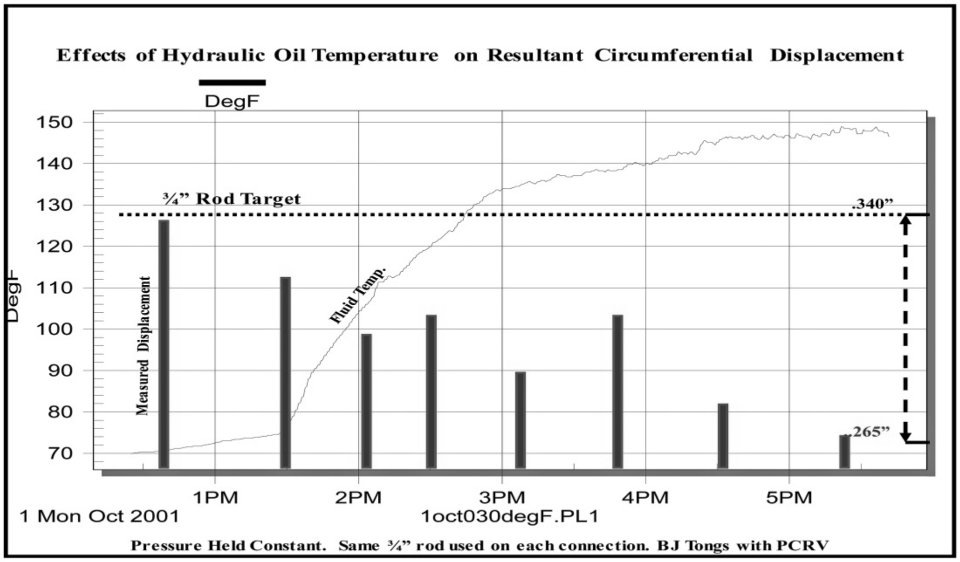

Figure 3 – Laboratory example of the effects of hydraulic power fluid temperature on circumferential displacement values. (REF. 2)

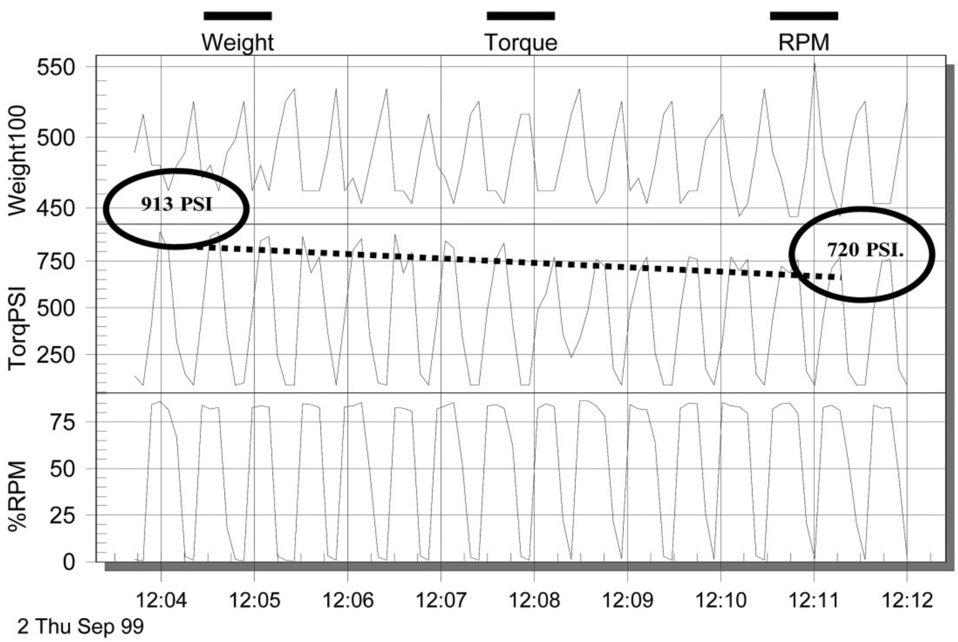

Figure 4 – Field example of flow rate, engine RPM and relief valve opening pressure on torque pressure. (REF. 2)

Figure 5 – example of applied thread lubricant.

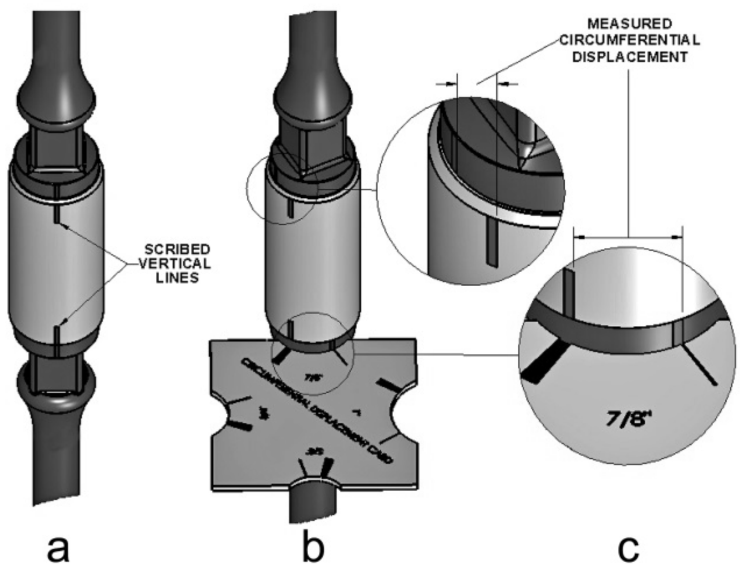

Figure 6 – a) scribe, mark or draw a vertical line across both pin shoulders and the corresponding coupling ends; b) using the appropriate CD card for the grade, size and condition of the rod, verify that the threaded connection meets the minimum required CD between the scribed vertical lines using the edge of the mark on the pin shoulder and the corresponding edge of the mark on the coupling for both coupling ends; and c) optimum pin preload stress is obtained when the minimum required CD is achieved for both coupling ends.