NEW DESIGN API MODIFIED SUCKER ROD CONNECTION AND METHODS AND SYSTEMS FOR PRECISE CONNECTION MAKE-UP

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ABSTRACT

The steel API sucker rod connection design used in beam and progressing cavity pumping systems has been an industry standard since the 1920's. During these many years of continuous use, improvements have been made both large and small, yet this three part connection system is responsible for the majority of rod string connection failures. After 3 ½ years of development, we now bring to the industry a new API modified four-part design with a method and system for precise make-up which expands load bearing capabilities and extends the working life of sucker rod connections. This paper describes development and testing work performed, information acquired, systems and methods created, and how the new API modified connection solves problems, eliminates or greatly extends time between failures, keeping work over and associated costs to a minimum. {See Figure - 1}

INTRODUCTION

API threaded sucker rod connections used in beam and progressing cavity pumping systems unlike the long smooth bodies of the rods between the upsets are a combination of forge formed and machined-in material stress concentrators. During the expected working life, these three part threaded systems are subjected to a multitude of mechanical alternating loads and forces resulting in a very complicated stress spectrum. It has been published in the industry that 99% of API rod connection failures are work cycle fatigue failures due to improper makeup. "Modem Sucker-Rod Pumping", by Gabor Takacs Ph.D.", Penn Well Publishing Company. API sucker rod working performance and time to failure is dependent on five factors, the basic design of the parts, the quality and processing of the material, proper forge forming of the end areas, machine work to design tolerances, and the final assembly and make-up into one unit. The economic goal is to have a rod connection system that when properly applied in the well design will provide a working life as close as possible to the rod body, which is without stress concentrators. {See Figure - 2)

THREE PART API SUCKER ROD CONNECTION – API STD. 11B

The sucker rod connection pin is that part of the forged rod end that is machined using the metal removal process. Modem computer controlled lathes and tungsten carbide cutting inserts are used to cut the pin form on each rod end. After the pin is cut to shape and dimension, the threads are cold forged on the pin end using the same lathe and an O.D. thread roll tool. The couplings are made from heavy wall rolled steel tubing, properly machine cut to form and dimension, and again the threads are cold forged using an I.D. roll tap. Couplings are made in two O.D. sizes, full-size and slim-hole which were designed to achieve maximum hydraulic efficiency in the minimum tubing I.D. using the maximum O.D. rod body. The number one cause of connection failure during pumping is relative movement between any two of the three parts. Movement in sucker rod connections is a function of the level of mechanical loads and forces, how they affect individual areas of each part of the connection, and how the resultant stresses are handled by the parts as a unit. Movement can only take place at the pin shoulder to coupling interface and at the engaged pin to coupling thread area. Any load or force that can produce a movement between mated parts, even at the crystalline structure, can cause permanent deformation that under continued work cycles only grows larger. The greater the frequency and differential in the tension load between downstroke and upstroke, the quicker the range of movement between the parts will grow, greatly reducing the connection fatigue life.

Then there are the most damaging loads, fluid or gas pounding, subjecting every connection in the rod string to shock and impact to some degree. Pounding loads are exactly that, instantaneous and hammer-like, and are concentrated at the pin shoulder to coupling end interface, then transferred down the undercut pin neck to the pin–coupling load flank thread helix interface. The three part API design has no pin end support, and as each pounding load reaches a connection, the pin shoulder to coupling end contact pressure incurs a large positive load spike, then continues down through the undercut pin neck aggravating the bending that was induced at make-up, and finally causing the pin-coupling load flank thread helix contact pressure to incur a large negative load spike. As each impact event takes place, microscopic deformations are produced in the pin shoulder-coupling interface and at the thread helix load flanks that increase in size with each additional pounding. There is a similar phenomenon in the torsion mode relative to the pin shoulder to coupling face and threaded area as pounding during progressive cavity pumping. This can occur when formation solids or any event takes place at the pump causing instant torque spikes that will continually urge the unsupported pin end threads to jack screw deeper into the coupling that could eventually cause pin failure. API connections with full size couplings, if made up properly, should tolerate abusive treatment longer than slim hole coupling connections made up properly due to the thicker cross section and larger pin shoulder contact end areas. The four part PRO-KC API Modified Connection design with the center torque button increases shock and impact load bearing area on full-size couplings 65-75%, and on slim-hole couplings 80-90%. When the pins are made up against the torque button, three benefits are gained. These benefits are firmly locked thread forms, eliminating any additional axial or radial movements; increase in the load bearing area over three part API design; and, providing a connection that is much more rigid, transferring shock and impact loads through its column like structure, through the coupling center torque button and into the adjoining rod. A detailed consideration of some of these factors is set forth in a report entitled "Finite Element Analysis of Sucker Rod Couplings With Guidelines For Improving Fatigue Life" by Edward L. Hoffman, identified as Sandia report "Sand97-1652.USC122" captioned "for Unlimited Release" and printed September, 1997 by Sandia National Laboratories, Albuquerque, New Mexico. This report contains recommendations for improving the characteristics of sucker rod couplings under practical operating conditions. In summary, it is emphasized that the primary objective is unit rigidity through proper induced make-up pre-stress and secure locking of the threaded elements, thus improving connection fatigue resistance.

CIRCUMFERENTIAL DISPLACEMENT MAKE-UP - API RP 11BR

This make-up method is recommended by the API and sucker rod manufacturers for proper make-up of sucker rod connections. The rods are stabbed into the couplings and made up to the hand-tight position. Then, a vertical line is scribed across the joint in two places, the distance between the lines being the circumferential movement required to insure joint tightness. Due to the difficulty of applying this make-up procedure as the rods are run into the well, or the vast amount of time consumed to apply this procedure to every connection on the rig, the crews, generally, mark and observe the make-ups on two or three connections, average the hydraulic pressure to the power tong during those make-ups and make-up the remaining connections to hydraulic tong pressure only. However, during the development of the PRO-KC four part connection system, it became obvious the circumferential displacement make-up system would rarely stretch the pin end to the same dimension from the pin shoulders. Since pin neck pre-load stretch is directly proportional to the pin shoulder to coupling end face contact pressure, thread tightness, and connection rigidity, this indicated further study and physical testing was necessary.
{See Figure - 3}

FOUR PART PRO-KC CONNECTION

The four part PRO-KC sucker rod connection system consists of two pins, one coupling and one coupling center torque button. This system can be applied to all new or inspected used rods and couplings. The pin ends of the rods, whether new or inspected used, are subjected to a wet magnetic particle inspection of the total pin end areas. {See Figure - 4} Then, both pin ends of each rod are machined to a precise dimension from shoulder to pin end, by removing only .010 to .035 of an inch from the chamfer area, and leaving some of the chamfer in place. The pin end now has a precise dimension from shoulder to pin end and the pin end is flat and parallel at 90 degrees to the pin shoulder to insure maximum load bearing area against the coupling center torque button. The coupling is also inspected and machined to a precise overall length dimension that insures that each end of the coupling is flat and parallel to the opposite end. At this time, the coupling end I.D. chamfer is remachined to API specifications, if necessary. {See Figures 5-A and 5-B} When the machine process is completed, all dimensional accuracy is confirmed through the use of calibrated micrometers to +/- .0005 inch. {See Figures 6-A and 6-B}

PRO-KC CONNECTION MAKE-UP SYSTEM AND METHOD

Detailed investigation of the circumferential displacement make-up system had revealed serious shortcomings. At that point it was determined that the correct amount of make-up pin neck pre-load stretch to effect sufficient pin shoulder to coupling end face contact pressure for each rod size and grade that would perform under all operating loads with a reasonable safety factor was not known. A program was enacted of strain gauged physical specimens where a series of loads and combinations of loads was applied and data was acquired. {See Figure - 7} This work did not lead to any definitive numbers, but did reveal a very interesting behavior between the pin/coupling thread helix that indicated the presence of various point or local contact areas along the length of the pin/coupling load flanks at the hand tight position. This type of mismatch between the two thread forms of any pidcoupling combination, new or used, and how these mated parts will react during make-up would appear to approach the infinitely variable. In order to confirm these indications to fact, a proprietary PRO-KC makeup/breakout unit was modified and a plunger type dial indicator to directly read pin advancement into the couplings was mounted and many connections, new couplings-new pins, new couplings-used pins, used couplings-used pins, were made-up to circumferential displacement specifications and dial indicator readings observed. After 1000 plus make-ups and indicator readings at displacement that varied from .0015 to .012 inch and everywhere in between, it became obvious that consistent preload neck stretch could not be dependably attained using this method. To better understand what was exactly taking place, 15 each, new couplings-new pins, new couplings-used pins, used couplings-used pins, (all specimens were 1-inch hi-strength), were cleaned, dried and a light coat of machinist blue dye applied to all the pin and coupling threads, made-up to hand tight, backed off and the threads inspected. The visual inspection was performed using a dentist mirror and magnification, which in every case revealed line, point, or various degrees of local load flank contact throughout the length of the thread helix. After each hand tight, the couplings were advanced circumferentially in .060 inch increments, backed out and inspected until the local deformations were pulled through and intimate contact of the load flanks was achieved along the full length of the thread helix. New couplings-new pins required the most advancement, new couplings-used pins less than the first case, and used couplings-used pins required the least advancement to achieve intimate flank contact. It was determined that the primary cause of these local deformations is the threads in the couplings and the thread roll tap that cold forges them. The term thread roll tap is a misnomer as there are no hardened roll disks present as in an external thread roll die head. The roll tap has serrated flutes or teeth-like stationary protrusions much like a cutting tap that must cold forge the coupling I.D. thread form through the length of the coupling. The extremely high friction and pressure point loads along with the associated heat and wear produce an ever changing thread form over its working life. Even though the roll tap remains within API tolerances for hundreds of parts, there is gradual thread form change. There is a vast difference between the first 10 couplings and the last 10 couplings produced using the same thread roll tap. With all the above information in hand, the necessary pre-load stress or the amount of pin neck stretch to achieve that stress, to insure maximum connection performance, was suspected, but as yet was still not known. At this time, an in depth Finite Element Analysis was contracted for, using ABAQUS, Revision 6.2, a 2D axisymmetric mesh, and an elasto-plastic material model consisting of a 1-inch size and hi-strength material and 1-inch slim hole "T" coupling. Models and processes like these are commonly used industry wide to predict future performance of threaded connections on tubing, casing, line pipe, and sub-sea risers systems, and do give a good comparison to existing sucker rod connection values. The suspected pin neck pre-stretch dimension was then entered into the model, and load cases in tension and compression were run. {See Figures 8, 9, and 10} Fluid or gas pounding shock and impact loads were not within the scope of this analysis. Final analysis indicated that physical testing was now warranted. All tests that followed were performed using pins and couplings dimensioned exactly as those in the model.

TESTING OF PHYSICAL SPECIMENS

Physical testing was initiated which included tension plus torsion to failure and tension plus compression to fatigue failure. The tension plus torsion tests were performed at CFER Laboratory, Edmonton, Alberta, Canada. I-inch hi-strength pins and slim hole "T" couplings were made up to PRO-KC connection make-up specifications. The connections were then installed in the test fixture. 20,000 lbs. tension was applied and maintained while torque was gradually added to the connection until failure occurred. After 18 tests, the four part PRO-KC API Modified design averaged over 250% more torque to failure than the comparable three part API connection design. {See Figure –11-A and 11-B}

All fatigue tests were performed at Southwest Research Institute, San Antonio, Texas. A total of 30 specimens was tested of which eight were three part API design and 22 were four part PRO-KC API modified design, all test specimens were API 1-inch, hi-strength material with 1-inch slim hole "T" couplings. The testing loads were tension 69,500 lbs., compression 7,800 lbs. at 10 load cycles per second. The specimens were tested in groups of four and five. Design changes for improved fatigue life were implemented from group to group. At the conclusion of these fatigue tests, the final two groups of PRO-KC API modified sucker rod connections averaged 600% more load cycles to failure than the comparable three part API design. {See Figures 12, 13, and 14)

In the course of modifying sucker rod connections to the PRO-KC four part configuration for beam and progressing cavity pumping applications in the Permian Basin area, an information gathering program was instituted that would enable the Circumferential Displacement Make-up Method to be compared to the PRO-KC Precision Make-up Method. Couplings were snapped on to the pins by hand and a line marked across the pin shoulder and onto the coupling, put in the make-up unit and the dial indicator zeroed. The pins were turned until the dial indicator needle reached the dimension required to achieve the proper amount of pre-load pin neck stretch and pin shoulder contact force. {See Figure – 15} The connection was removed from the make-up unit and the distance the line on the pin shoulder had moved circumferentially from the line on the coupling was measured with dial calipers and recorded. This task was performed on 980 1-inch hi-strength new and used inspected rods, all the couplings were new slim hole "T" class. {See Figure – 16) Also made-up, measured, and recorded were 1270 718-inch hi-strength used inspected rods, all couplings were new full size "T" class. {See Figure – 17) Since all rods in this program were hi-strength, the Circumferential Displacement dimension used was the manufactures recommended. This provides an accurate comparison of the two basic designs and make-up methods over 2250 specimens and is presented in this paper for industry critic and further evaluation.

CONCLUSION

The Industry has been well served since 1926 when the three part API sucker rod connection design was first standardized by the API.

The PRO-KC API modified design and make-up system provides the Industry a sucker rod connection system that is stable, with no relative movement between coupling and pin, having 65-90% more load bearing and friction area, rod shoulder plus pin end. Using the preload pin neck stretch method, the coupling is held and the rod pin end is turned into the coupling and the threads advanced along the helix to a point that imparts the proper pin shoulder to coupling end face contact pressure and pin neck preload stretch. Pins are advanced into the couplings against a dial indicator plunger to insure exact dimensional pin end placement and preload neck stretch. The coupling torque button is installed and locked in place against the pin end which insures that the pin end that is made up at the rig will always be the end that breaks out. When made up at the rig site, thread lube is lightly applied, stabbed and made up hand-tight. At the hand-tight position, there is a gap between the pin end and the torque button that is the exact dimensional amount of the preload neck stretch of the pin already made up in the other side of the coupling. The pin is then turned down the thread helix until the pin end firmly contacts the torque button, which is a very obvious event. This gives the same amount of preload neck stretch on both pins in that coupling. The specified additional amount of pin end to button torque that induces the proper amount of preload stretch at the center of the coupling is then applied. The pins are loaded against the torque button and create a pre-stressed column like structure through the coupling.

The research and development described in this paper consisting of strain gauged specimen work, Finite Element Analysis, tension plus torque to failure testing, and the extensive amount of fatigue testing of the four part PRO-KC API modified design proves the ability of this connection and make-up system to handle tension, torsion, bending, compression, and shock and impact loads greatly exceeding the performance of the standard API configuration.