# VALIDATION OF FRICTION COEFFICIENTS AND WEAR CONCEPTS IN SUCKER ROD LIFT SYSTEMS -- ENGINEERED SOLUTIONS TO REDUCE TUBING WEAR FAILURES

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## ABSTRACT

In some of today's highly deviated wells, sucker rod pumping systems are facing challenges related to excessive wear that interrupt production and increase artificial lift costs. One of the reoccurring failures in a sucker rod pumped well occurs in areas of the rod string where contact between the sucker rod connection and the tubing is pronounced by side loads. Wear from both metal contact and abrasive particles flowing around the rod string, and corrosive attack from the wellbore's fluid also affects the metal integrity of the tubing, coupling, guides, and sucker rods. Proper rod guiding configurations helps to delay the metal-to-metal contact between the rod string and tubing, but guide material properties should be carefully designed to increase guide life while preventing excessive tubing wear that lead to hole-in-tubing. This paper is intended to provide additional fundamental understanding on wear and friction concepts for rod lift applications, and address some of the important factors that should be included in the approach to develop new materials and systems to reduce tubing wear-associated failures.

## INTRODUCTION

Thousands of the wells that are drilled every year in the US are highly deviated with significant localized dog leg severities. Sucker rod pumping has been a cost-effective method to artificially lift vertical and some deviated wells. However, the combined effect of severe mechanical wear due to well deviation and the harsh wellbore conditions are some of the contributing factors that encourage operators to consider other methods of artificial lift that are generally more expensive and complex. The well intervention frequency in sucker rod pumping systems can be around 12-18 months. Nonetheless, highly deviated wells and corrosive wellbore fluids make interventions more frequent.

Failures in sucker rod pumping systems deserve dedicated attention from manufacturers in today's corrosive and demanding well conditions. The need of some metrics for coupling materials that balance corrosion, wear, abrasion properties, and COF will be of great advantage for operators who are trying to select the best materials for their well that will reduce the tubing and coupling wear, optimize the susceptibility to corrosion-related failures, and optimize the rod string design in predictive software programs.

In this paper, wear damage on couplings and on tubing are measured using downhole wear testers. COF from different materials in different fluid environments are experimentally determined and result trends are discussed. The testing approach is presented as a method to measure emerging coupling and guide technologies vs. conventional solutions under various operating conditions. Lastly, effectiveness of rod string rotator systems to maximize usage of guide erodible wear volume is evaluated.

## DISCUSSION

### Material Wear

There are various types of wear including abrasive, adhesive, erosive, contact fatigue, fretting, corrosive, and interfacial. From the rod lift engineering perspective, only abrasive wear and adhesive wear are discussed in this paper.

- Abrasive wear, as defined by ASTM, is due to had particles or hard protuberances that are forced against and move along a solid surface. Wear, in turn, is defined as damage to a solid surface that generally involves progressive loss of material and is due to relative motion between that surface and a contacting substance or substances [1]. Examples of abrasive wear are gouging, grinding, scratching, and polishing. It can be limited to the two bodies in the definition that move relative to each other or it can include a third body or asperity such as sand in between a reciprocating sucker rod and stationary tubing ID.
- Adhesive wear occurs when multiple surfaces maintain frictional contact causing microscopic welding at the interface resulting in unwanted displacement and attachment of wear debris.

Coefficient of Friction (COF)

Coefficient of friction is not a consistent, clearly defined materials property in real world application. It is highly dependent on the nature and cleanliness of the surfaces, surface roughness, and measuring condition. In other words, coefficient of friction is a system property. Surface Topography (macrodeviations, waviness, roughness) and mechanical and chemical properties of surfaces (hardness, alloy segregation, chemisorption) are some of the important factors that affect friction coefficient load. In rod lift system, the fluid media and the sideload also influence the COF value.

Friction force includes static, kinetic, rolling, air and viscous. This paper focuses on static and kinetic friction only. Friction force is a force between two surfaces that prevents or slows those surfaces from sliding or slipping across each other. For example, when rod string goes reciprocates inside of the tubing, in deviated wells the rod string will be in contact with the tubing inner surface which will results in frictional forces. Friction force is, generally, a function of the friction coefficient and the reacting force of a body's weight or applied load perpendicular to the intended direction of friction. This reaction is also known as the normal force. The following equation represents the fundamental correlation between friction coefficient, normal force and friction force. Friction coefficients are highly dependent on the material tribological properties of the two surfaces in contact.

$$F_f = \mu F_n$$

Where:
$F_f$ is the frictional force
$F_n$ is the normal force
$\mu$ is the coefficient of friction (COF)

A coefficient of friction is a value that shows the relationship between the force of friction between two objects and the normal reaction between the objects that are involved. Friction often transforms the energy of motion into thermal energy or the erosion of moving surfaces. Therefore, reducing the coefficient of friction of materials can reduce the frictional force and drag forces in the pumping unit and increase the efficiency of the pumping unit.

Material Properties Affecting COF/Wear Rate in Rod Lift System

COF and wear in a rod lift application are generally associated with the hardness differences between the coupling surface and the tubing. The class T coupling has a hardness around 18-20 HRC, the Spray Metal coupling has a surface hardness of 55-60 HRC. The typical J55, L80, or N80 tubing has a hardness of 20-23 HRC. The metal component with the lower hardness is said to be sacrificial. Although the class T coupling seem to be the solution to the tubing wear problem, corrosive environments can reduce the life of the coupling to 3-6 months. Although, the hardness is a good indicator of wear, the surface finish can also affect the flow of solids around the connection (i.e., the smoother surface, the faster particle will slide through the coupling OD). Furthermore, thermal conductivity will also impact the wear rate of the material, due to localize wear created during friction. In the case of guides, using polymer materials, it is important to understand how the material strength and stability is affected by temperature. Differential scanning calorimetry (DSC) is a test used to measure heat flow versus temperature on polymers. Glass transition and melting temperatures will determine the maximum localized temperature that the polymer can stand with stable conditions.

## COF AND TUBING WEAR BENCHMARK TESTING

Tubing and Coupling Wear Damage Experimental Simulator – Reciprocating Applications

Wear tests are performed at the Norris facility in Tulsa, shown in figure 1. The wear tester used simulates wellbore environment with elevated temperature and presence of sand particles. Weight loss, major radius reduction and tubing thickness reduction, under applied side load, are measured as a function of number of strokes. The test fixture was a previous design located at the Norris Rod facility in Tulsa, Oklahoma. This equipment has been used in the past by major operators to test and validate wear on lined tubing technologies. Tubing carriers were immersed in water during the test. Sucker rod couplings were held against the tubing ID with various weights ranging from 50 to 250 pounds to simulate side loads as the tubing reciprocated back and forth in the carriers.

Case Study: Figure 2 shows the comparison of three types of couplings, namely Norris Corrosion Service and Tubing Friendly (CS-TF) coupling, nickel-tin high cost coupling, and class T coupling. Their effect on tubing thickness reduction and material wear. Left graph shows the coupling wall thickness and right graph shows the tubing thickness reduction. Figure 3 shows the wear surface morphology of couplings and tubing after tests. The Norris CS-TF coupling had the lowest tubing wear for side loads ~ 50lbs and the lowest material loss than the other couplings.

Tubing and Coupling Wear Damage Experimental Simulator – PCP Applications

Tubing wear with PCP rod strings are also a concern to customers and the Norris Rods facility in Tulsa, OK, has a system (figure 4) to test tubing wear from couplings and guides in similar PCP downhole conditions. Brine concentration, sideload, and rotational speed are the input parameters. The torsional friction with the tubing, material wear, and tubing thickness reduction are the performance indicators used to rate surface engineered materials.

Case Study: Figure 5 shows tubing torsional friction data for three types of couplings using 70-lb sideload, 250 RPM, brine salinity ~ 30%. The Norris CS-TF coupling show an improvement in torsional friction of up to 30% compared to other commercially available couplings.

Figure 6 shows the worn topography of couplings and tubing after tests. The Norris CS-TF leaves a scar on the tubing with smoother surface finish.

Linear Wear Rate and COF

Figure 7 shows the tribometer system used to perform accurate and repeatable friction and wear testing. To precisely measure wear track volume, a non-contact optical profiler module is used to quantify wear rate in a fast and convenient manner without removing the sample. Samples are extracted from finished couplings or guides so they are representative of the surface condition wearing against tubing.

Case study: A COF test following modified ASTM G133 was performed by a certified third-party lab to measure COF and linear wear rate under various fluid environments. Trends in figure 8 comparing two polymers indicate COF and wear rates are not just dependent on the surface hardness, but also on the type of wellbore fluid.

## DISTRIBUTION OF WEAR THOUGH ROD ROTATORS IN HIGHLY DEVIATED WELLS

Rod rotators have been used to gradually rotate the sucker rod string, as the string reciprocates, to evenly distribute frictional wear on components such as sucker rod, tubing, couplings, and guides. Figure 9 shows the effect of dog leg severity on concentricity of rod string with the tubing which creates torsional restriction that must be overcome to rotate the string. Figure 9 also illustrates the one-sided wear seen on most of the highly deviated wells using rod rotators, leaving most of the guides' erodible wear volume unused.

The thousands of rod rotators utilized in highly deviated wells are being reported as ineffective at rotating the rod string, resulting in one-sided rod string wear are shown in figure 10, as well as tubing localized wear measured during caliper logging.

The reason rod rotators do not work in highly deviated wells is that they attempt to drive the polished rod clamp rotation through surface friction. The friction force is transmitted from the gear to the top cap, and from the cap to the polished rod clamp. Figure 11 shows the surface friction interactions in a rod rotator system.

There are two types of friction conditions, static friction and kinetic friction. The force of static friction keeps a stationary object at rest, which is what the conventional top cap relies on to continue to rotate the string without sliding between the clamp and top cap, or between bottom of top cap and gear. Once the force applied is greater than the static friction force, as in the case of highly deviated wells, there will be a sliding motion either between the top cap and worm gear or between the top cap and polished rod clamp. In this condition there is kinetic friction between the contact surfaces, but it does not allow the torque to be properly transmitted from the gear set to the rod string and the torque output from the rod rotator is lost in surface friction. This is sometimes noticed in the wear track of the top conventional caps in field repair shops.

The most appropriate concept to correlate frictional forces from the rod rotator and clamp surfaces and torque transmitted on a sucker rod string is that of a friction clutch. The torque capacity of a clutch is a function of the normal force applied, the friction coefficient, and surface contact areas. The cases below show the maximum torque that can be transmitted through friction for different conditions of downstroke load. Case one and two show common Minimum Polished Rod Loads, in which the maximum torque that can be transmitted to the smallest HF clamp before slipping is ~300 ft-lbf.

Table 1 – Rod String Torsional Drag for Different Minimum Polished Rod Load

| | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 |
|---|---|---|---|---|---|
| $F_{MPRL}$ [lbf] | 5,000 | 10,000 | 15,000 | 20,000 | 25,000 |
| T [ft-lbf] | 141 | 282 | 423 | 564 | 705 |

It has been estimated thought PCP systems that wells with deviations between 53° to 80° angles (3.4°-4.5° dog leg severities) require 800 ft-lbf torsional drag to rotate the string [3]. When the torsional drag from the well deviation is greater that the frictional torque output, the rod string does not rotate and the uniform distribution of wear in the tubing, couplings, and guides cease making the system more susceptible to faster tubing wear failures. This led to the motivation of designing a system that can have a higher output torque. Especially for wells as those found in South Texas where the kick-off to the deviated section of the well is set rather higher in the string close to surface. One study carried out in South America showed that in highly deviated wells the drag torque is about 800 ft-lb [3]. Under this high drag torque conventional rod rotators are not capable to rotate the rod string and evenly distribute wear.

Norris developed a patent-pending solution (figure 12) with a polished rod clamp lock-in system to effectively rotate the string without relying on friction. The bottom part of the clamp is received by the diamond-shaped inset region, the inner sides walls of the diamond-shaped inset region is providing a pushing force to the side walls of the polished rod clamp in addition to the frictional force. In this way, the top cap transmits a guaranteed rotation movement to clamp as it rotates itself. There is also an internal linkage mechanism to connect the the gear and the cap without sliding of the two surfaces.

CONCLUSIONS

Wear and COF are system properties. Materials should be engineered accordingly for well downhole conditions (e.g., high sideloads, $H_2S$ corrosion). Norris coupling, and guide material technology development is primarily focused on tubing wear while maintaining acceptable integrity on the couplings and guides. Surface engineered couplings and guides should be evaluated through benchmark testing under different wellbore fluid environments, temperatures and sideloads, that include the most severe conditions, before engaging into a field test.

For highly deviated wells where wear is challenging, Norris' new sophisticated rod rotator will maximize the use of erodible wear volume by rotating the string without relying on friction.

<u>REFERENCES</u>


[1] ASM Handbook, Volume 18: Friction, Lubrication and Wear Technology, 1998.
[2] Successful PCP Applications in High Deviated Wells: Breaking Away the Paradigm of PCP Only for Vertical or Low Deviated Wells in Colombia. SPE 165053. Hipatia Cuella (Petrominerales) et. al., SPE Artificial Lift Conference-Americas, 21-22 May, Cartagena, Colombia.


Figure 1 – Norris reciprocating tubing wear testers

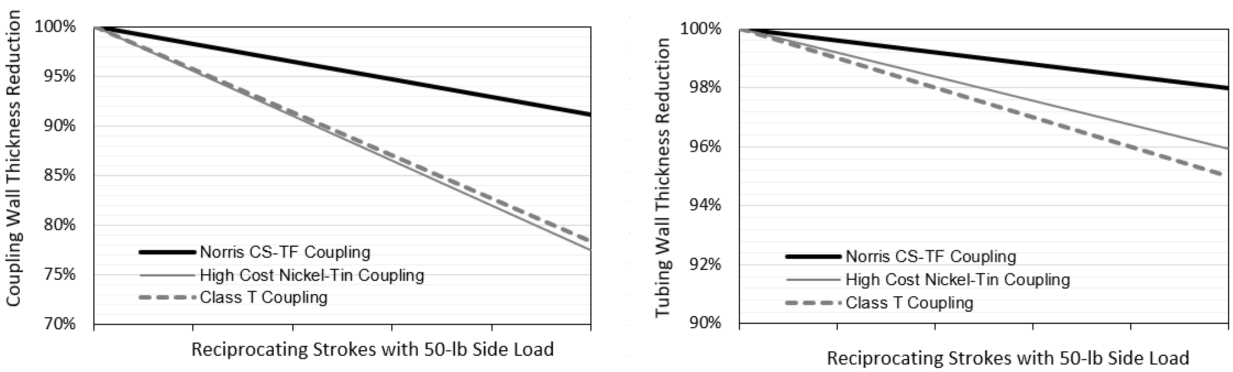


Figure 2 – Coupling (left) and tubing (right) reciprocating wear profiles with 50-lb side load


Figure 3 – Coupling (left) and tubing (right) wear morphology

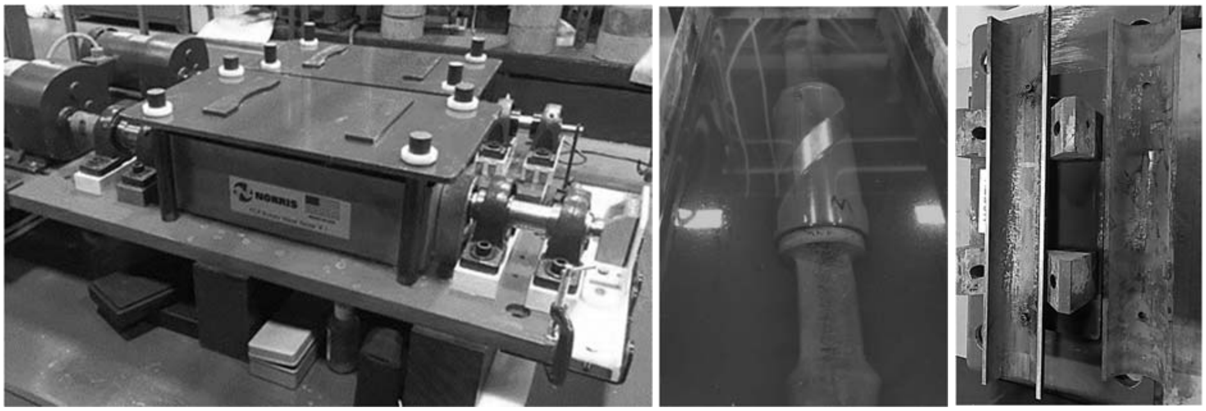

Figure 4 – Norris PCP rotary wear testers

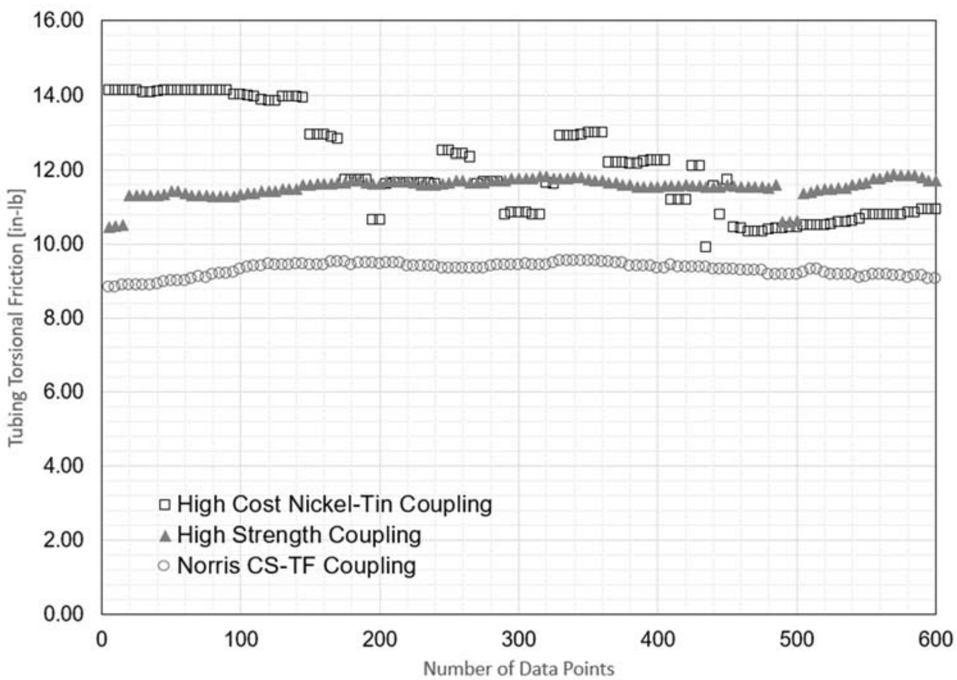


Figure 5 – Tubing torsional friction with 70-lb side load and 250 RPM

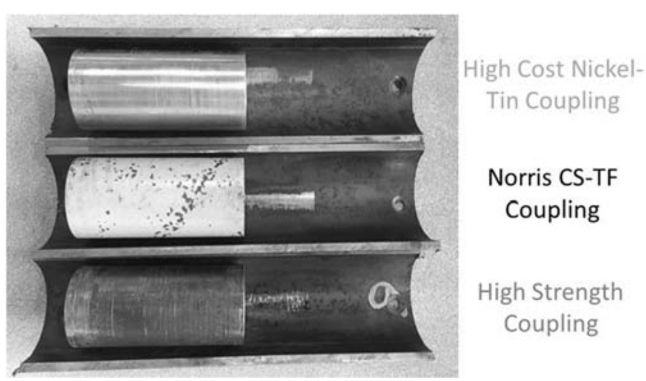


Figure 6 - Coupling and tubing wear morphology from torsional friction tests

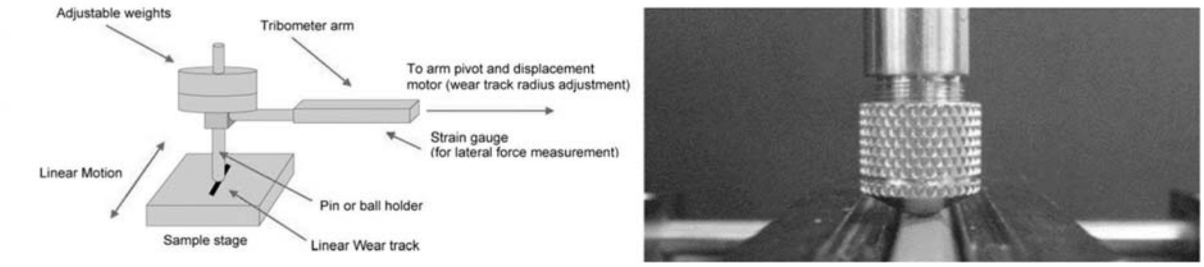


Figure 7 – Linear COF testing system schematic

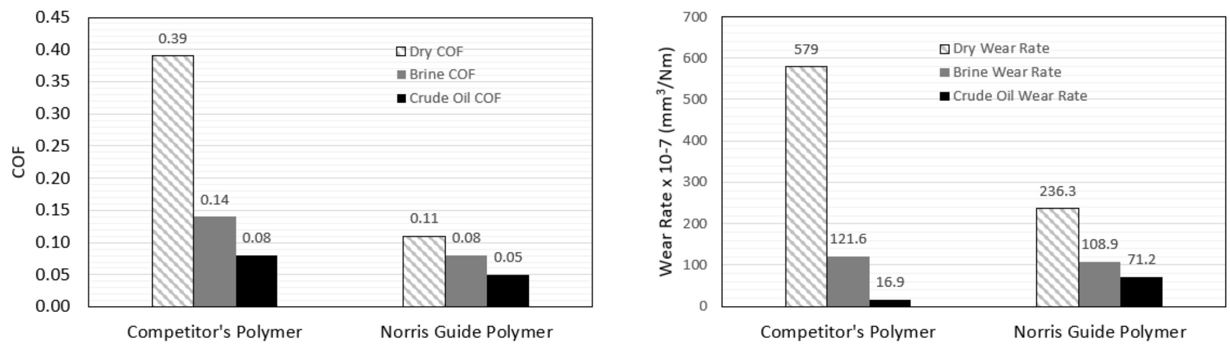


Figure 8 – COF (left) and linear wear rate (right) values for dry, brine and crude oil environments

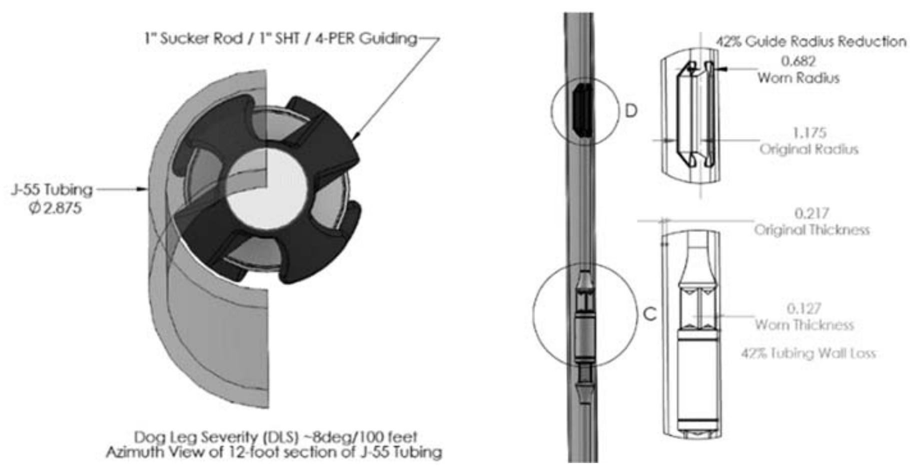


Figure 9 – One-sided rod string wear in highly deviated wells due to localized dog leg (~8deg/100 feet)

Figure 10 – One-sided rod string wear with friction-dependent rod rotators

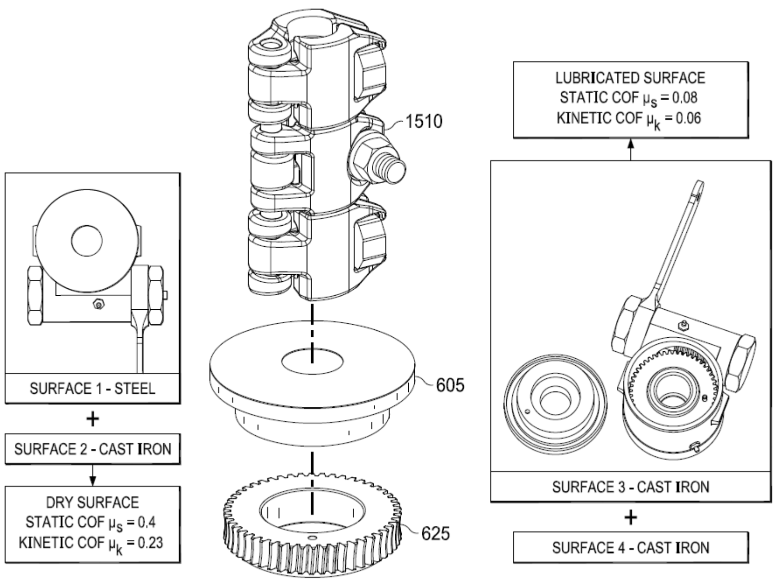


Figure 11 – Friction diagram for conventional rod rotators


Figure 12 – Norris slow gear rotator with polished rod clamp lock-in System