

Rod Rotator Torque in Rod Strings

**Dean Smith
Flow Control Equipment, Inc.
A Unit of Robbins & Myers, Inc.**

Abstract

In the last several years, the question has been frequently raised as to how much torque can a typical rod rotator transfer to a rod string. This is an especially important consideration for fiberglass rods. This paper discusses testing on three popular rod rotator models, the T-164TM, T-252TM, and T-302TM, plus an optional version, designated as T-302SGTM (slow gear version). The test results are based on carrier bar loads versus output torque measured at the instant that slippage occurs at the frictional interface located between the worm gear or ratchet table and the cover cap of the various rod rotator designs.

In addition, a case history involving a new, positive drive version known as a "T-302 No-Slip" Rod Rotator, for situations involving extreme wear on one side of rod guides, will be discussed. This new style of rod rotator uses special components to lock the worm gear to the cover cap and also to prevent the rod clamp from slipping on top of the cover cap.

Introduction

This project had two objectives. The primary objective was to determine if torque generated by any of the four rod rotators studied could damage steel or fiberglass sucker rods. The second was to measure the number of strokes required for each rotator to turn the rod string one revolution.

Flow Control Equipment Inc. (FCE) rod rotators depend on two frictional interfaces, which are shown in the exploded view of the heavy duty T-302 rod rotator in Figure 1 of the Appendix, to transmit rotary motion and torque to the rod string. The first interface is located internally between the drive gear (worm gear) and the bottom of the cover cap. The second interface is located externally between the top of the cover cap and the bottom of the polished rod clamp. These two planes of friction are actually clutches or torque limiters. As a result, the amount of torque that can be transmitted to the rod string is governed by the minimum carrier bar load pressing the surfaces together, the areas of the surfaces in contact and the coefficient of friction between the surfaces.

FCE tested its standard T-164, T-252 and T-302 rod rotators plus its newest version of the T-302, the T-302SG, for output torque versus carrier bar load. At each carrier bar load, the actuator lever was pulled until slippage occurred at the internal interface. At that point, the maximum output torque transmitted to the cover cap was recorded for each load.

At the same time the torque tests were conducted, it was convenient to determine the number of strokes a pumping unit would make for each rotation of the rod string. Based on the assumption that the actuator lever shown in Figure 1 is set to rotate 1/4 turn or 90° every time the pumping unit makes one stroke (one complete revolution of the cranks), the number of pumping unit strokes per revolution of the rod string was also determined as shown in Table 2.

Rod Rotator Testing Procedure

A test fixture was built to simulate the polished rod load. A hydraulic cylinder was used to impose a known force upon a rod clamp resting on top of the cover cap. Each load was measured and recorded by using a pressure transducer and strip chart recorder. The actuator level was then activated until

slippage at one of the frictional interfaces occurred. The output torque at each load was determined by attaching a moment arm of known length to the polished rod and measuring the force at the end of this arm. The forces on the moment arm were also measured with a load cell and recorded on a strip chart. Finally, output torque was calculated for each simulated polished rod load by multiplying the force at the end of the moment arm by the length of the moment arm. To insure accuracy, prior to the actual rotator tests, the "frame friction", was measured in the test fixture without a rotator installed. The torque due solely to the frictional resistance of the test fixture (or frame) was factored out of the recorded torque values for each rotator by means of linear regression analysis. The test fixture is illustrated in Figure 2.

Torque Limitations For Sucker Rods

There are three cases to be considered to determine how much torque a string of sucker rods can withstand. The first two involve steel sucker rods. The third involves fiberglass rods.

In the first case, the amount of torque required to permanently yield the sucker rod body must be considered. The second case involves the maximum torque that is permitted to make up the pin and box connection. In some rod grades and sizes, yield strength of the rod body is the limiting factor. In other grades and sizes, allowable makeup torque sets the limit.

The third and last consideration is the torque that is allowed on the bond between the metal pin connectors and the fiberglass bodies.

Case 1. The torque required to cause failure in a solid cylindrical steel body can be calculated from the formula:

$$T_{fp} = 4 \tau_{yp} J / (3 R_o) \quad (\text{Ref. 1})$$

T_{fp} is torque in in-lbs., R_o is one half of the rod diameter in inches, and J is the centroidal polar moment of inertia. τ_{yp} is the maximum allowable shear stress of the material, and is obtained by multiplying the minimum yield strength of a given steel in tension by 0.577 (Octahedral Shear Theory - Ref. 2)

For a solid cylindrical cross section: $J = \pi R_o^4 / 2$

Substituting this expression into the above torque equation results in the following equation:

$$T_{fp} = (2/3) \pi R_o^3 \tau_{yp}$$

For API Grades C and K, the minimum yield in tension is 60,000 psi (Ref. 3)

For API Grade D, the minimum yield in tension is 85,000 psi (Ref. 3)

For API grades C and K: $\tau_{yp} = 0.577 \times 60,000 \text{ PSI} = 34,620 \text{ PSI}$

For API grade D: $\tau_{yp} = 0.577 \times 85,000 \text{ PSI} = 49,045 \text{ PSI}$

For 5/8" API grades C and K the max. torque is: $(2/3) \pi (0.3125)^3 (34,620) = 2214 \text{ In-Lbs}$ or 185 Ft-Lbs.

The results of the calculations for various rod sizes and grades are shown in Table 1.

Case 2. The recommended make-up torque for sucker rod box and pin connections is found in Table 4 on page 39 of Reference 4. These are recommended torque values which were developed by the API Subcommittee on Sucker Rods in late 1959 and 1960. These values theoretically preload the pin connections to a working load of the sucker rod, which is based upon maximum allowable stresses of at least 35,000 psi and higher. The results are also tabulated in Table 1. The lower number is the API recommendation for rods with maximum rod stress of 35,000 psi and the higher number is for rods subjected to stress greater than 35,000 psi.

Case 3. All three manufacturers of fiberglass rods show 100 Ft-Lbs as the maximum allowable torque for fiberglass rods. (Ref. 5,6, and 7)

Table 1. Calculated Rod Body Torque Limits, Published API Coupling Make-up Torque Values, and Manufacturers Published Torque Limit for FRP (Fiberglass) Sucker Rods

Rod Size	API Grade	Case 1 Rod Body Torsional Limit (Ft-Lbs)	Case 2 Coupling Make-up Torque (Ft-Lbs)	Case 3 FRP Rods - Metal End Fitting to Rod Body Limit (Ft-Lbs)
5/8"	C & K	185	220 - 242	---
5/8"	D	262	220 - 242	---
3/4"	C & K	319	350 - 385	---
3/4"	D	452	350 - 385	---
7/8"	C & K	506	520 - 572	---
7/8"	D	717	520 - 572	---
1"	C & K	756	800 - 880	---
1"	D	1071	800 - 880	---
1-1/8"	C & K	1076	1100 - 1210	---
1-1/8"	D	1524	1100 - 1210	---
3/4" - 1-1/4"	FRP	---	---	100

Table 2. Maximum Load Rating and Number of 90° Turns of Ratchet Lever Per Revolution of Rod String

Model	T-164	T-252	T-302	T-302SG	MD-300
Max. Load (Lbs)	13,000	33,000	40,000	40,000	33,000
No. of Turns	28	24	77	154	160

Test Results

One notable result was that in every case, the plane of slippage was at the internal friction interface between the bottom of the cover cap and the top of the T-252 ratchet table or the drive gear (worm gear) in the T-164, T-302, and T-302SG models. At the point of maximum torque, the slippage never occurred in the friction plane between the bottom of the polished rod clamp and the top of the cover plate. Any combination of torque and load, which causes slippage results in cover cap stall.

Taken literally, the results indicate that maximum output torque for the T-164, T-252 and T-302SG fall between 105 and 134 Ft-Lbs for carrier bar loads up to 20,000 Lbs. As expected, the relationship between output torque and carrier bar load was essentially linear over the test range for each rotator.

However, the linear relationship changed dramatically at 10,000 Lbs., 12,000 Lbs. and 18,000 Lbs. for the T-252, T-164 and T-302SG, respectively. The leveling off points in the torque and load (T-L) curves, shown in Figure 3, were a surprise and cannot be adequately explained from data collected during these tests.

Behavior of the T-L curve in Figure 3 for the T-302 rotator was more in line with expectations in that it was linear throughout the zero to 20,000 lb. test horizon. But, the slope of the T-L curve for the T-302 was greater than the slope of the T-L curve for the T-302SG. The magnitude of this difference is surprising because the internal frictional interfaces for both rotators are dimensionally identical. The fact that the T-302SG is geared to rotate at half the speed of the T-302 should not have had an effect on the results. One possibility which would explain the difference is that the coefficient of friction was less for the T-302SG.

Table 3. Comparison of Rod Torque Limits Versus Rotator Output Torque at Maximum Load Rating of the Rod Rotator or 20,000 Lbs.

Rod Size and Grade	Maximum Allowable Torque * (Ft-Lbs)	T-164 @ 13,000 Lb. Load (Ft-Lbs)	T-252 @ 20,000 Lb. Load (Ft-Lbs)	T-302 @ 20,000 Lb. Load (Ft-Lbs)	T-302SG @ 20,000 Lb. Load (Ft-Lbs)
5/8" C,K	185	105	120	240	134
5/8" D	220	105	120	240	134
3/4" C,K	319	105	120	240	134
3/4" D	350	105	120	240	134
7/8" C,K	506	105	120	240	134
7/8" D	520	105	120	240	134
1" C,K	756	105	120	240	134
1" D	800	105	120	240	134
1-1/8" C,K	1076	105	120	240	134
1-1/8" D	1100	105	120	240	134
3/4" - 1-1/4" FRP	100	105	120	240	134

* smallest value of Case 1 and Case 2.

Conclusions

Variations in the slopes of T-L curves for the T-302 and T-302SG rotators coupled with unexpected discontinuities in the T-L curves for the T-164, T-252 and T-302 rotators clearly suggest that additional testing is required before the boundaries of maximum output torque can be completely defined. As a result, additional tests are being planned. Even so, the project yielded enough information that it is possible to draw some conclusions with a reasonable degree of certainty.

Prior to addressing the remaining conclusions, it is important to understand that the maximum load rating for each rod rotator shown in Table 2 should be matched with peak, not minimum polished rod loads. It is also important to remember that maximum output torque will coincide with minimum, not maximum carrier bar loads. In other words, maximum torque cannot be determined without knowing the minimum carrier bar load which is always less than the peak polished rod load. In most real world situations, as will be discussed later, the primary concern is generally not excess torque in the rod string but rather carrier bar loads so low that the rotator cap stalls.

In the case of the T-164, which has the least load capacity, the maximum output torque is 105 Ft-Lbs. Even if the minimum carrier bar load was equal to the rotator's capacity of 13,000 Lbs., which constitutes an overloaded situation, the output torque is still below the torque ratings for any steel sucker rod. The T-164 could be operated safely on fiberglass rods as long as the peak polished rod load did not exceed the capacity rating of 13,000 Lbs. However, the MD-300, which will be discussed later, is the rotator of choice for fiberglass rods because it features more precise control over output torque. Therefore, another notable conclusion is none of the T-Series rotators except the T-164 are recommended for fiberglass rods.

Test results can easily lead to speculation that the maximum output torque for the T-252 is low. If the straight line portion of the T-252's T-L curve in Figure 2 is extrapolated to 20,000 Lbs., it's conceivable the maximum torque could be in the range of 200 Ft-Lbs. rather than 120 Ft-Lbs. Even then, the T-252 rotator would exceed only the torque limits for 5/8" C, K, rods. For minimum carrier bar loads in excess of 20,000 Lbs., the peak polished rod load will likely exceed the 33,000 lb. load capacity of the T-252 rotator.

The T-302 rotator could exceed torque limits for 5/8" rods, if 5/8" had sufficient yield strength to generate a minimum carrier bar load in the range of 20,000 Lbs. But this is not possible. Even if it was, the T-302 is an overkill for 5/8" rods and should not be used. Generally, the minimum rod size requiring the heavy duty T-302 is 7/8". Even at twice the maximum output torque of 240 Ft-Lbs. at 20,000 Lbs., the output torque of a T-302 would still be below the 506 Ft-Lb. rating for 7/8" C, K, rods as shown in Table 2.

In summary, none of the rod rotators studied can generate excess torque in steel sucker rod strings if the proper rotator is selected for the job. With the possible exception of the T-164, none of the T-Series rotators should be used on fiberglass sucker rods.

New Developments in Rod Rotator Design

MD-300 Rod Rotator

FCE recently added the MD-300™, which rotates the rod string on the upstroke, rather than the down stroke like the "T-Series" rotators. During the down stroke a ratchet mechanism disengages the actuator lever from the worm drive shaft as the actuator cable raises the lever. During the upstroke the weight of the actuator lever alone causes rotation. If the weight of the actuator lever is not sufficient to rotate the rod string, then an optional lever counterweight is added to increase torque. This allows precise torque adjustments by the operator. This unique torque adjustment capability makes this model an excellent choice for fiberglass sucker rods. The MD-300 is illustrated in Figure 4.

"No Slip" Rod Rotators

As mentioned earlier, stalled rotators are more likely to be encountered in the field than over torqued rod strings. A "stall" situation usually involves wells with highly deviated well bores. In these cases, the minimum carrier bar load is so low that the internal friction interface will slip before enough torque can be applied to rotate the rod string. The usual symptom of this condition is uneven wear on the rod string. High side loads cause enough resistance that conventional rotators stall. As a result, rotators fail to distribute wear evenly on the rod guides. The solution to this problem has been the introduction of the "No-Slip" or positive drive rotator shown in Figure 5. A field test of a well experiencing a one-sided wear problem is shown in Table 4.

Well Data:

Location: Huntington Beach, California
 Pump Depth: 4775'
 Rod taper: 78 7/8" and 80 3/4"
 SPM: 9
 Stroke Length: 98"
 Pump Size: 2.5"
 Fluid Characteristics: 120 BTFPD/18 BOPD API 15 gravity oil
 Maximum Well Bore Deviation: 47° @ 3032'
 Maximum Dog-Leg: 7.3' @ 1109'
 Maximum Side Load: 450 Lbs.

Table 4. Pull History

Year	1992	1993	1994	1995	1996	1997
Month/Day	-	12/7	-	8/2	-	7/31
No. of Pulls	2	1	6	1	0	1
Tubing Joints Replaced	151	153*	2	0	0	0
No. of Rods Replaced	186	90	225	159***	0	78
No. of Rod Guides Installed & Location (6 per rod)	None	45 3/4" on bottom	**	Guided Top to Bottom	Guided Top to Bottom	Guided Top to Bottom
Size & Type of Guide	None	2.5" TB	**	3" AFNETB	3" AFNETB	3" AFNETB
Rod Rotator	None	None	None	T302 No-Slip	T302 No-Slip	T302 No-Slip

Legend: TB - standard FCE Turbulence Breaker™ rod guides.

AFNETB - New Era Turbulence Breaker (NETB™) rod guides, PPA material

* Tubing Size was changed to 3-1/2"

** On 3-22-94 57 2.5" TB guides were installed on 7/8" rods. On 10-18-94 replaced 9 bare & 4 guided 7/8" rods plus 43 3/4" guided rods with 3" AFNETB.

*** One side wear was observed on rod guides & T-302 No-Slip was first installed on 8-2-95 to prevent reoccurrence.

Comments and Observations:

Since the installation of the T-302 No-Slip Rotator, the well pumped from August 2, 1995 through July 31, 1997 (over 720 days) without failure. After the last work-over no one-sided rod guide wear was detected. Only the 7/8" rods needed to be replaced, and this was due to normal, evenly distributed wear of the rod guides. Another notable observation is how the installation of rod guides on the entire rod string dramatically reduced the number of tubing joints wearing out prematurely.

Acknowledgments

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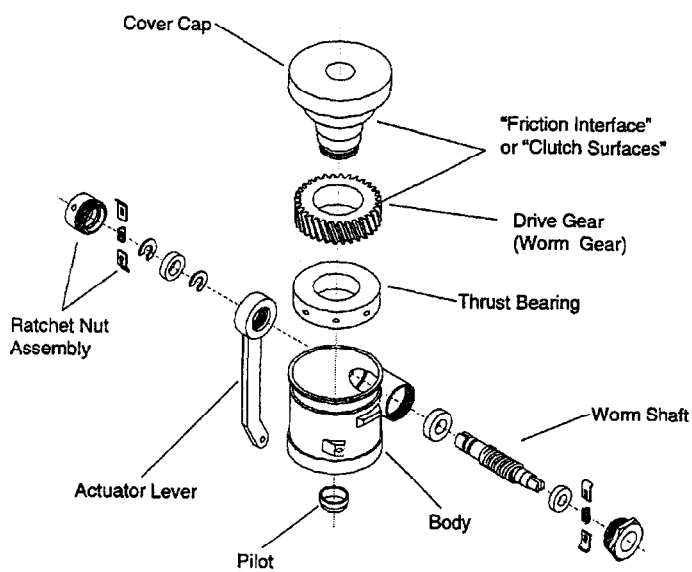


Figure 1 - T-302 Rod Rotator

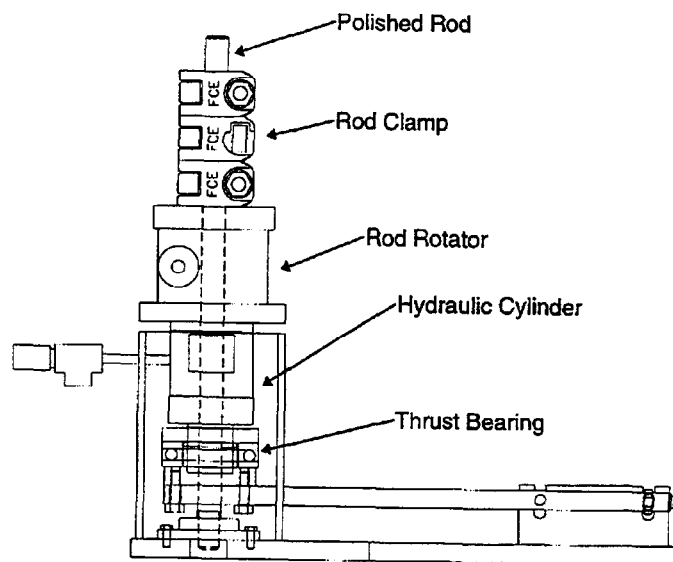
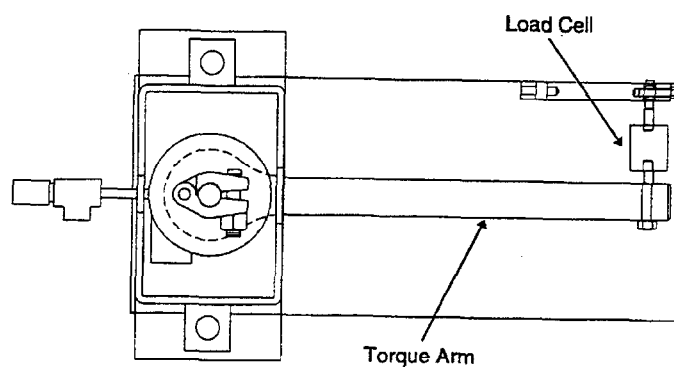


Figure 2 - Rod Rotator Test Fixture

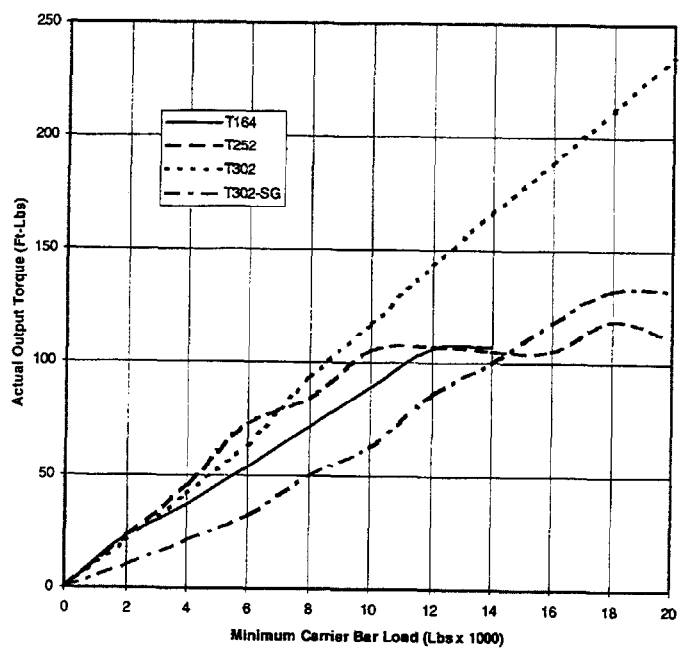


Figure 3 - Rod Rotator Torque vs. Carrier Bar Load

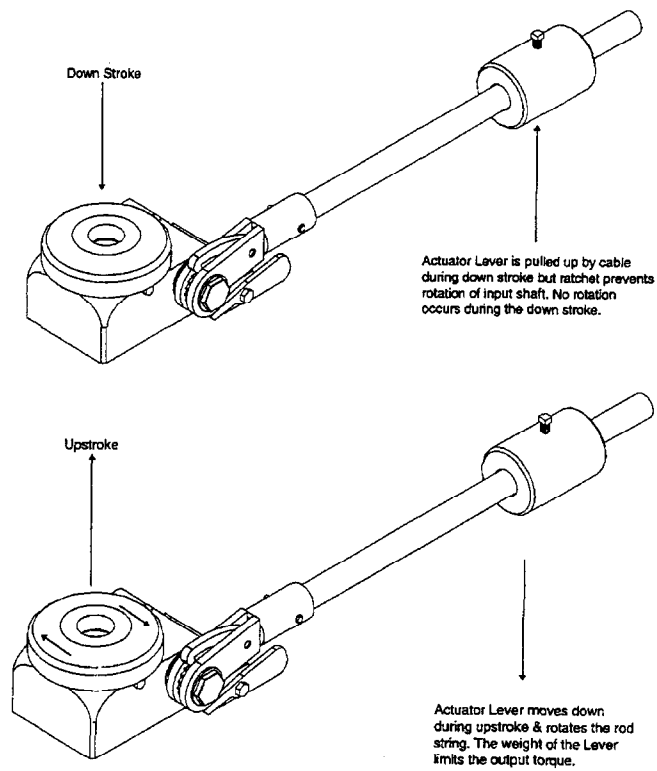
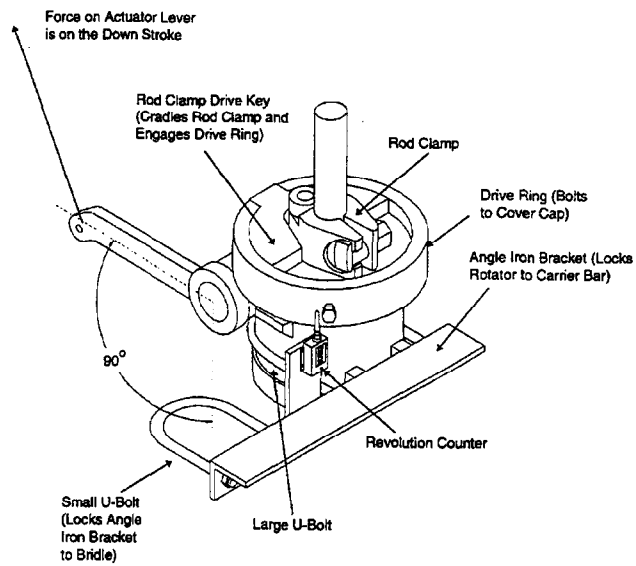


Figure 4 - M-300 Rod Rotator



NOTE
 In addition to the external parts shown in this diagram, T-252 and T-302 Rod Rotators must be internally modified for "No-Slip" application. Modified Cover Cap & Ratchet Table required for T-252. T-302 requires modified Drive Gear and Cover Cap.

Figure 5 - T-302 "No Slip" Rod Rotator