

## **THE EFFECT OF THE ARTICULATING INERTIAL TORQUE ON THE PERMISSIBLE LOADS OF SUCKER-ROD PUMPING UNITS**

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**Abstract:** The investigation of the overloading of sucker-rod pumping unit speed reducers can be carried out comparing the permissible loads and the actual loads on the polished rod gained from a dynamometer survey. The present paper investigates the effect of the consideration of the articulating inertial torque in the permissible load calculation.

**Keywords:** *sucker-rod pumping unit, articulating inertia, permissible loads*

### **1. INTRODUCTION**

The sucker-rod pumping units produce liquid from a well by operating a subsurface positive displacement pump with a rod string. The pumping speed of these units ranging from 2 to 15 SPM. The unit is usually powered by an electric motor, which has very high speed (~1000 RPM). To transform the high speed and low torque output of the motor into a slow speed and high torque a speed reducer is used. The speed reducer – or gearbox – has a maximal torsional loading – called rating – which should not be exceeded during the operation of the pumping unit. In order to determine whether a given unit is overloaded a measurement has to be carried out using a dynamometer. From the dynamometer survey the permissible loads corresponding to measured points in the upstroke and downstroke has to be found. Comparing the actual loads acting on the polished rod gained from the measurement and the calculated permissible loads the overloaded hypothesis can be accepted or declined. Previous papers covered this method by taking only the rod torque and counterbalance torque into account. The present work aims to investigate the effect of including the articulating inertial torque in the calculation process.

### **2. PREVIOUS WORKS**

The mechanical net gearbox torque is found by summing the different torque components. Neglecting the articulating inertial effect the following expression describes the torsional loading of the speed reducer [1]:

$$T_{net} = T_{rod} + T_{cb} = TF(\theta) \cdot (F(\theta) - SU) - T_{cbm} \cdot \sin(\theta) \quad 1$$

By substituting the rating of the gearbox – as the maximal net torque – into this equation the permissible loads – the maximal force acting on the polished rod – can be expressed:

$$F_p(\theta) = \frac{T_{rat} + T_{cbm} \cdot \sin(\theta)}{TF(\theta)} + SU \quad 2$$

Plotting the calculated permissible loads as a function of position of rods the result of the dynamometer survey can be evaluated. When the result of the dynamometer survey cuts the permissible load curve the unit is overloaded. Operating a pumping unit while the gearbox is overloaded can reduce its lifetime and increase the operating costs greatly. It can lead to a replacement, which is costly and the production has to be stopped till a new component is found.

### 3. CONSIDERING THE ARTICULATING INERTIAL TORQUE

Including the articulating inertial torque in the net torque calculation the following equation is gained.

$$T_{net} = TF(\theta) \cdot (F(\theta) - SU) - T_{cbm} \cdot \sin(\theta) + \frac{12}{32.2} \frac{I_B \cdot TF(\theta)}{A} \frac{d^2\theta_b}{dt^2} \quad 3$$

From Eq. 4 the permissible loads considering the investigated inertial effect can be obtained.

$$F_p(\theta) = \frac{T_{rat} + T_{cbm} \cdot \sin(\theta)}{TF(\theta)} + SU - \frac{12}{32.2} \frac{I_B}{A} \frac{d^2\theta_b}{dt^2} \quad 4$$

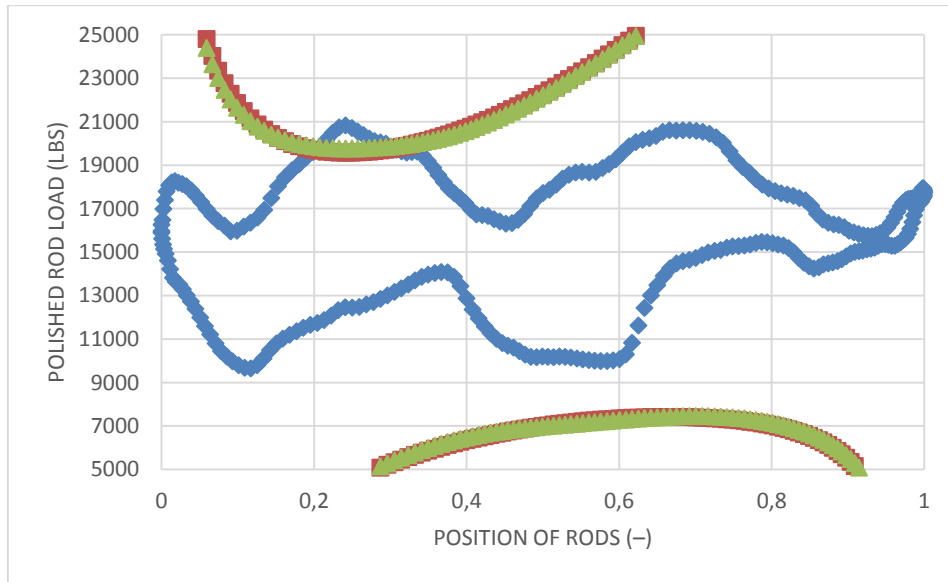
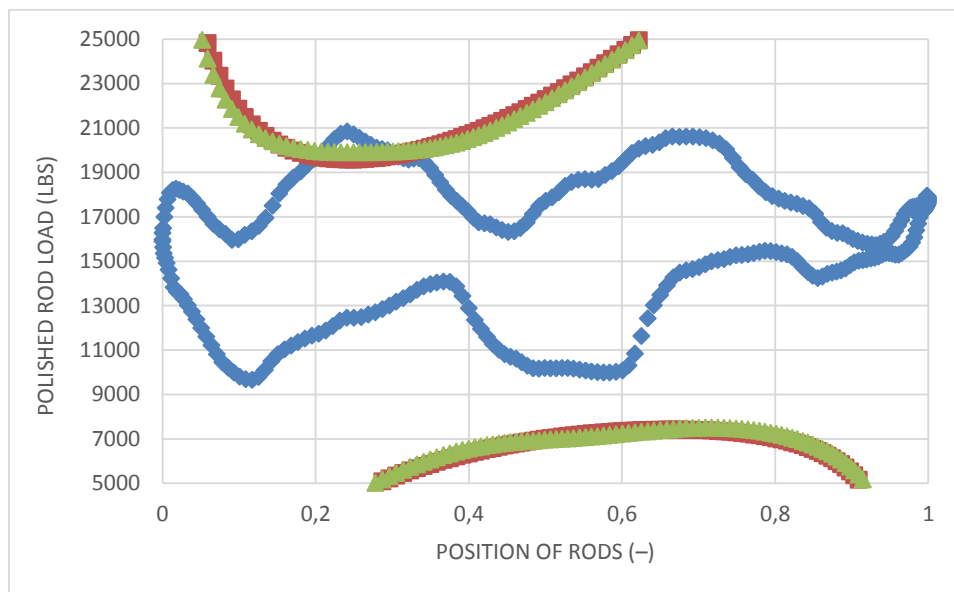


Figure 1.  
Dynamometer survey of the example problem (6 SPM)

The permissible loads considering and neglecting the inertial effects are plotted in Figure 1. The investigated pumping unit is a C-640D-365-168 conventional pumping unit with a 6 SPM pumping speed. The mass moment of inertia of the alternating moving parts is 951,889 lb/ft<sup>2</sup>. The maximal counterbalance torque is 1,387,000 in lbs. Additionally the beam angular acceleration pattern is required for the calculation, which is found from the polished rod displacement vs. time points. This calculation method is presented in [2] in detail.

During the operation of a sucker-rod pumping unit some parts have alternating movement throughout the pumping cycle. This phenomenon is valid for every pumping unit geometry, because the conversion of the rotational motion of the motor into the required purely alternating movement of the polished rod – and the rod string – cannot be achieved differently. Because of this phenomenon the articulating inertial torque will arise, which will affect the net torsional loading of the gearbox.

The beam acceleration pattern can be determined using the method first proposed by Svinos [3]. For the calculation the crank angle vs. time points are required, those are obtained using a numerical successive approximation method from the measured polished rod positions. [4, 5, 6] Greater crank angular speed produce greater beam acceleration, therefore the investigation range was extended to 10 and 15 SPM as well.



*Figure 2.*  
The change in the permissible loads (10 SPM)

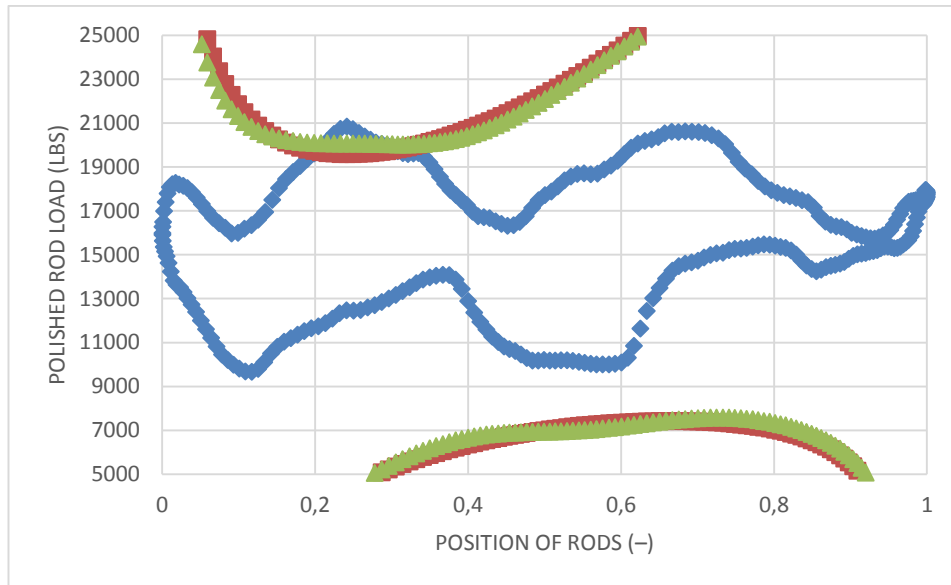


Figure 3.

The change in the permissible loads (15 SPM)

As seen in Figure 2 the effect of the consideration of inertia is noticeable. The squares refer to the previous calculation method, whereas the triangles correspond to the new method. The minimal permissible load in the upstroke is reduced with the inertial effect. This phenomenon is valid for Figure 3 as well, where the difference is even greater. The articulating inertial effect changes the permissible loads by approximately 4.5% at the 15 SPM case.

#### 4. CONCLUSIONS

The consideration of the articulating inertial torque alters the permissible load diagram. The change is proportional to the beam acceleration, which is different for every pumping speed. The magnitude of the resulting difference depends on the unit specification and the counterweight distribution. The greatest relative deviation is 4.5% for the solved example problem. Considering the articulating inertial effect in the permissible load calculation can lead to a better evaluation of the dynamometer survey. The minimal permissible load in the upstroke is reduced by the articulating inertial torque in the investigated case.

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## LIST OF SYMBOLS

Symbol	Definition	Unit
$A$	distance between the saddle bearing and the polished rod	in
$F(\theta)$	polished rod load at crank angle $\theta$	lbs
$I_b$	mass moment of inertia of the beam, horsehead, equalizer, bearings, and pitmans, referred to the saddle bearing	lbm ft <sup>2</sup>
$SU$	structural unbalance of the pumping unit	lbs
$T_{cbm}$	maximum moment of counterweights and cranks	in lbs
$T_{net}(\theta)$	net torque on the gearbox at the crank angle $\theta$	in lbs
$T_{rat}(\theta)$	torque rating of the gearbox	in lbs
$TF(\theta)$	torque factor at the crank angle $\theta$	in
$d^2\theta/dt^2$	angular acceleration of the beam	1/sec <sup>2</sup>
$\theta$	crank angle	degrees