Best Method
to Balance
Net Torque Loading
on a Pumping Unit
Gearbox
Reduced Gear Life Relative to % Overload

Life, years

Percent Overload

Lufkin
Reasons to Properly Counter Balance Gearbox Loading

1) Reduce Operating Expenses
2) Minimize Torque Loading on Gearbox and Not Exceed Gearbox Load Rating
3) More Uniform Torque Loading throughout Stroke
4) Minimize Energy Cost
5) Minimize Prime Mover Requirements
6) Do not Damage Artificial Lift Equipment
Three Methods Available to Determine Net Gearbox Torque Loading

1) Use Input Motor Power, motor and drive efficiencies and the pumping unit speed

2) Use surface dynamometer card and torque factors together with counterbalance moments determined from static counterbalance effect, CBE, test.

3) Use surface dynamometer card and torque factors together with counterbalance moments from the crank and weights.
Three Methods to Determine Gearbox Loading
Well #1 Acquired AMPs

KW
Well #1 Acquired Load

Acceleration
Motor Net Gearbox Torque Behaves Same as Mechanical Net Gearbox Torque

Well #1 Plot of Power and Mechanical Torque Data

Both show unit weight heavy (overbalanced)

Counterweights need to move in from the end of the crank to balance the peak torques
More Uniform Torque Loading Throughout Stroke

Mechanical/Torque (in-lbs) or Electrical/Power (kW) Signatures for a Unbalanced or Balanced Pumping Unit:
Acquire Electric Power (kW) and Current (Amps) Input to the Motor over the time of a Pump Stroke
Use $T_N = 84.5 \times kW \times Eff / (SPM \times SV)$ to Calculate Net Gearbox Torque.
Power Balancing Considerations

• Measurement of power using the power-current transducer is a quick and easy process

• For more efficient operations power requirement on the upstroke should be balanced against the downstroke

• Operator does not have to know the pumping unit API dimensions, weight of counterbalance, or center of gravities; all that is needed, is to know is the weight of the counterbalance that must be moved
Determine Mechanical Net Gearbox Torque Defined by API Standard 11-E

Torque Factor Method is the Standard Method to Determine the Instantaneous Torque Throughout the Pumping Cycle

Use:
- Polished Rod Load and Position Data
- Torque Factors
- Together with Counterbalance Moments
Dynamometer Outputs Polished Rod Load/Position Applied to Unit Over One Complete Stroke
Torque Factors

1. Unit API Dimensions Hand Entered or Selected From a Data Base

2. Torque factors (TF) are derived from the geometry of the particular pumping unit

3. Used to determine the instantaneous torque due to polished rod load at a given crank position.
Select API Dimensions From Data Base

Pumping Unit Library Editor

Manufacturer: Lufkin Conventional
Class: Conventional
API: C-320D-256-100

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<th>Gearbox</th>
<th>Structural Load</th>
<th>Stroke Length</th>
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<td>A</td>
<td>129 in</td>
<td>R1: 42 in</td>
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<td>P</td>
<td>132 in</td>
<td>R2: 36 in</td>
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<td>K</td>
<td>175.5 in</td>
<td>R3: 30 in</td>
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<td>Structural Unbalance: 550 lb</td>
<td>R4: 24 in</td>
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Comment: 

Done
Save
Diagram
Torque Factors Derived from Geometry of Selected Pumping Unit
Torque due to Polished Rod Load

Net well load is:

\[ W_N = \text{net well load} = (W - SU) \]

Torque due to net well load is:

\[ T_{WN} = TF \times W_N \]

Where:

- \( W = \text{well load at a specific crank angle} \)
- \( SU = \text{structural unbalance of the pumping unit} \) (either plus or minus value)
- \( TF = \text{torque factor, inches} \)
Counterbalance Moment, $Me$, from CBE

$$Me = TF_{90} \times (CBE - SU) / \sin (\theta + \tau)$$

Where:

- $Me$ = existing counterbalance moment of the crank and counter weights
- $CBE$ = well load at 90 Deg crank angle
- $SU$ = structural unbalance of the pumping unit (either plus or minus value)
- $TF_{90}$ = torque factor at 90 Deg crank angle
- $\theta$ = the crank angle (90)
- $\tau$ = the crank phase angle
Field Measured CBE with Crank Level
Example Well #1

Polished rod load trace versus time, where unit stopped on upstroke with cranks level

At 137.2 sec
Counter Balance Effect Load: 11024.6 lbf
Calculated Bouyant Rod Weight: 8040.76 lbf
Calculated Bouyant Rod Weight + Fluid Load: 12062.1 lbf
Determine Mechanical Net Gearbox Torque
Defined by API Standard 11-E

Torque Factor Method is the Standard Method to Determine the Instantaneous Torque Throughout the Pumping Cycle

Use:

- Polished Rod Load and Position Data
- Torque Factors
- Together with Counterbalance Moments
Calculate Counterbalance Moment for Conventional Pumping Units with Crank Mounted Counterweights

Note:
For convenience only one Counterweight is shown on the top of the crank (this is the #1 Counterweight).

\[
Me = Mcr + \sum_{i=1}^{Nm} Wm_i \times (Dcg - X_i) + \sum_{i=1}^{Na} Wa_i \times (Dcg - X_i)
\]
Counterbalance moment for conventional cranks is the sum of the moments contributed by the cranks themselves (Weight x Center-of-Gravity) plus the moments of the master and auxiliary weights.

Example Well #1 (2 x 8495B Cranks with 4 x 3CRO Master Weights):

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<tr>
<th>Name</th>
<th>Crank #1</th>
<th>Crank #2</th>
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<td>Weight (Lbs)</td>
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<td>Center Gravity (CG) (inches)</td>
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<td>Mcr, Crank Moment (in-lbs):</td>
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<table>
<thead>
<tr>
<th>Name</th>
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<td>CG - inches</td>
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<tr>
<td>M. W. Moment (in-lbs):</td>
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Total Moment: \[2 \times 162,338 + 4 \times 44,056 = 500,900 \text{ in-lbs}\]
Select Cranks and Counter Weights

Calculate:

Sum the moments contributed by the cranks themselves

(Weight x Center-of-Gravity)

Plus the moments of the master and auxiliary weights.

Counter Balance Moment Existing
Torque due to Counterbalance Moment CBE or CBM

\[ T_{CN} = M \times \sin (\theta + \tau) \]

Where:

- \( M \) = existing counterbalance moment of the crank and counter weights
- \( \theta \) = the crank angle
- \( \tau \) = the crank phase angle
Net Gearbox Torque, $T_N$

Difference between the torque due to net well load and the torque due to the counterbalance moment of the crank and counterweights:

$$T_N = TF \times W_N - M \times \sin (\theta + \tau)$$
Net Gearbox Torque, $T_N$

$$T_N = TF(W - SU) - M \sin(\theta + \tau)$$

- $T_N$ = net gearbox torque (inch-lbs)
- $TF$ = torque factor at crank angle $\theta$, (in-lbs)/lbs = inch
- $W$ = polished rod load at $\theta$, (lbs)
- SU = structural unbalance of unit (if negative, head falls, lbs)
- $M$ = maximum counter weight moment (in-lbs)
- $\theta$ = crank angle (degrees)
- $\tau$ = crank offset angle (degrees)
\[ T_N = TF(W - SU) - M \sin(\theta + \tau) \]

**Torque Factor:**
From tables or calculated, \((\text{in-lbf})/\text{lbf}, \text{each load & position})

**Load**

**Position**

**Structural unbalance, Lbf, if negative, head falls**

\[ M = RxW @ 90^\circ \]

\( \tau = \text{Fixed Offset Angle} \)

\( \text{ie: Mark Unit} \)
### Example of API Standard 11-E Calculations

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<th>(1) Crank Angle Deg</th>
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<th>(5) Well Load (Lbs)</th>
<th>(6) Structural Unbalance (Lbs)</th>
<th>(7) Col 5-6 Net PRL (Lbs)</th>
<th>(8) Torque Factor (In)</th>
<th>(9) Col 7x8 Well Torque (In-Lbs)</th>
<th>(10) C.B. Moment (In-Lbs)</th>
<th>(11) Col 4x10 C.B. Torque (In-Lbs)</th>
<th>(12) Col 9-11 Net Torque (In-Lbs)</th>
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Plot of API Standard 11-E Calculations

\[ M \sin(\theta + \tau) \]

\[ T_N \]

\[ TF(W - SU) \]
Both Power and Mechanical Show Gearbox to be Weight Heavy (overbalanced)

Well #1 Plot of Power and Mechanical Torque Data

Counterweights need to move in from the end of the crank to balance the peak torques
Determine Counterbalance Moment, $M$, to Balance Peak Torques Between Upstroke and Downstroke

Balancing the peak torques done by equating the upstroke peak, $T_{Nu}$, to the downstroke peak, $T_{Nd}$.

Solving for the counterbalance moment that makes the two peak torques equal ($T_{Nd} = T_{Nu}$).

$$M = \frac{[TF_d \times (W_d - SU) - TF_u \times (W_u - SU)]}{[\sin (\theta_d + \tau) - \sin (\theta_u + \tau)]}$$
Select Mechanical Torque Method

For Net Torque Calculations Use:

- Counter Balance Effect (Weights level)
  - 11.0246 Klb

- Counter Balance Moment (Existing)
  - 500.9 Kin-lb

Weight Of Counter Weights: 5324 lb

Manufacturer: Lufkin Conventional
Unit Class: Conventional
API: C-320D-256-100
Stroke Length: 100 in
Rotation: CW, CCW
Net Gearbox Torque - Mechanical

Net Torque (K-in-Lbs) [Balanced]

Permissible Load (K-Lbs) vs Position (in)

Net Torque (K-in-Lbs) [Existing]

CBM

Rating | Peak Balanced | Peak Existing
--- | --- | ---
Gearbox | 320000 | 210569.5 | 229344.1 in-lb

Counter Balance Change:
- Decrease for Balance: 19150.2 in-lb
- Weight of Counterweights to be Moved: 5308 lb

Move Counterweights IN 3.6 in

From Their Present Location To Balance Unit

Stroke 1
Net Gearbox Torque - Mechanical

Permissible Load (K-Lbs) vs Position (in) for HT5019:

- Gearbox:
  - Rating: 320000 in-lb
  - Peak Balanced: 210569.5 in-lb
  - Peak Existing: 256629.8 in-lb

Counter Balance Change:
- Decrease: For Balance 46981.6 in-lb
- Weight of Counterweights To Be Moved: 5308 lb
- Move Counterweights: IN 8.9 in

Net Torque (K-in-Lbs) [Balanced] and [Existing]:

- CBE

Overlay Power Data: Yes
# Net Gearbox Torque - Power

**Torque Calculation:**

\[ \text{Torque} = 84.5 \times P \text{ [KW]} \times \text{EFF} / (\text{SPM} \times \text{SV}) \]

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Counter Balance Change For Balanced Torque: 21.0

**Weight Of Counterweights To Be Moved:**

5308 lb

For Adjusted Torque Move Counterweights:

IN 4.0 in

**Strokes Per Minute (SPM):** 8.4

**Motor/Belts Efficiency (EFF):** 0.8

**Speed Variation (SV):** 0.94

**Gearbox Rating:** 320000 in-lb
Distance to be Moved Marked on Crank for “Weight of Counterweights to be Moved”

Initial Location of Weights Marked on Crank Arm Using a Yellow Paint Marker.

Distance Measured from End of Crank to Move Weight Is Marked On The Master Weight.

Second Mark Placed On the Crank Identifies the Location Service Company Will Use to Align the Outside Edge Of the Weight When Moved.