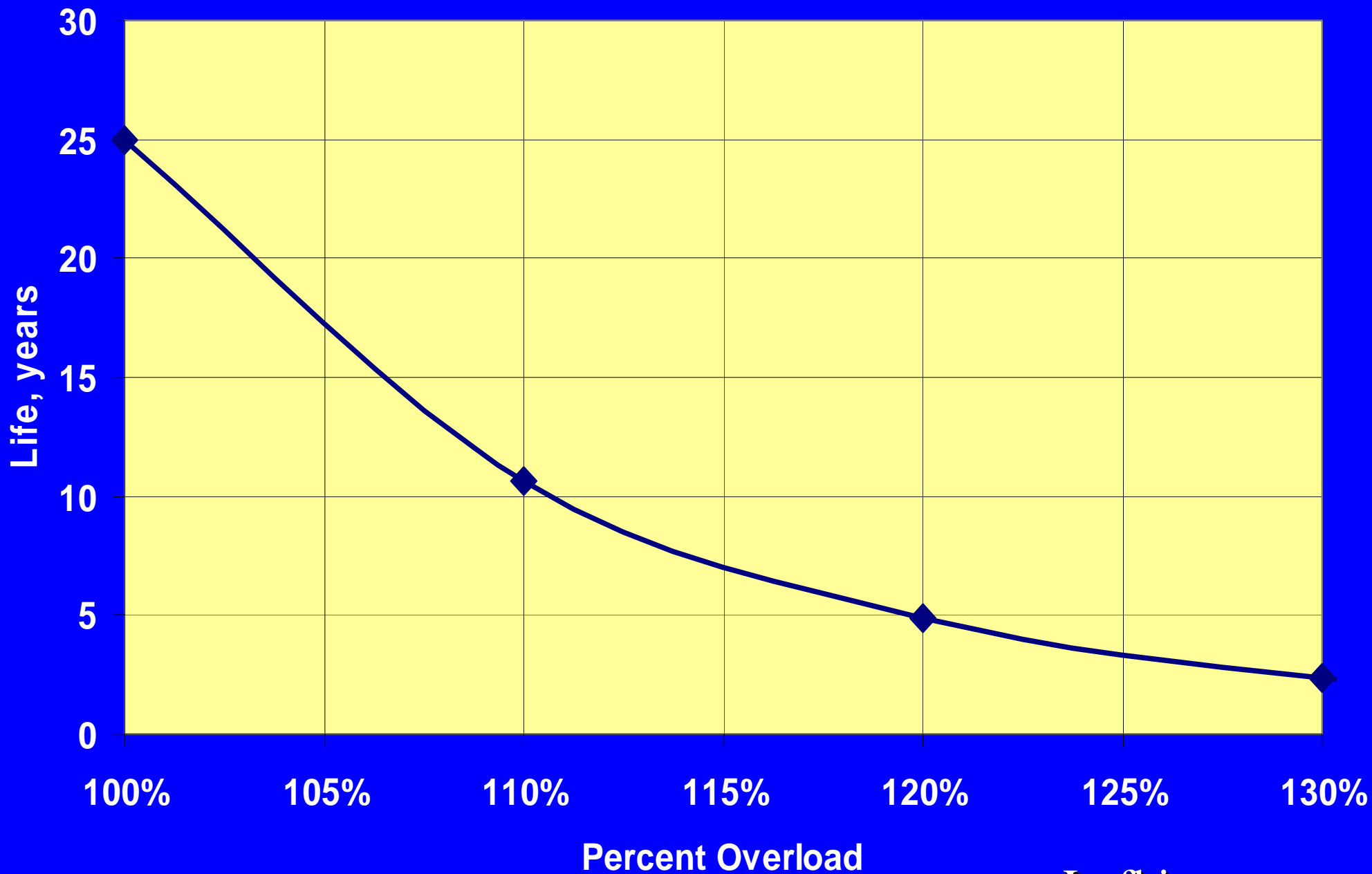


**Best Method
to Balance
Net Torque Loading
on a Pumping Unit
Gearbox**

Reduced Gear Life Relative to % 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**

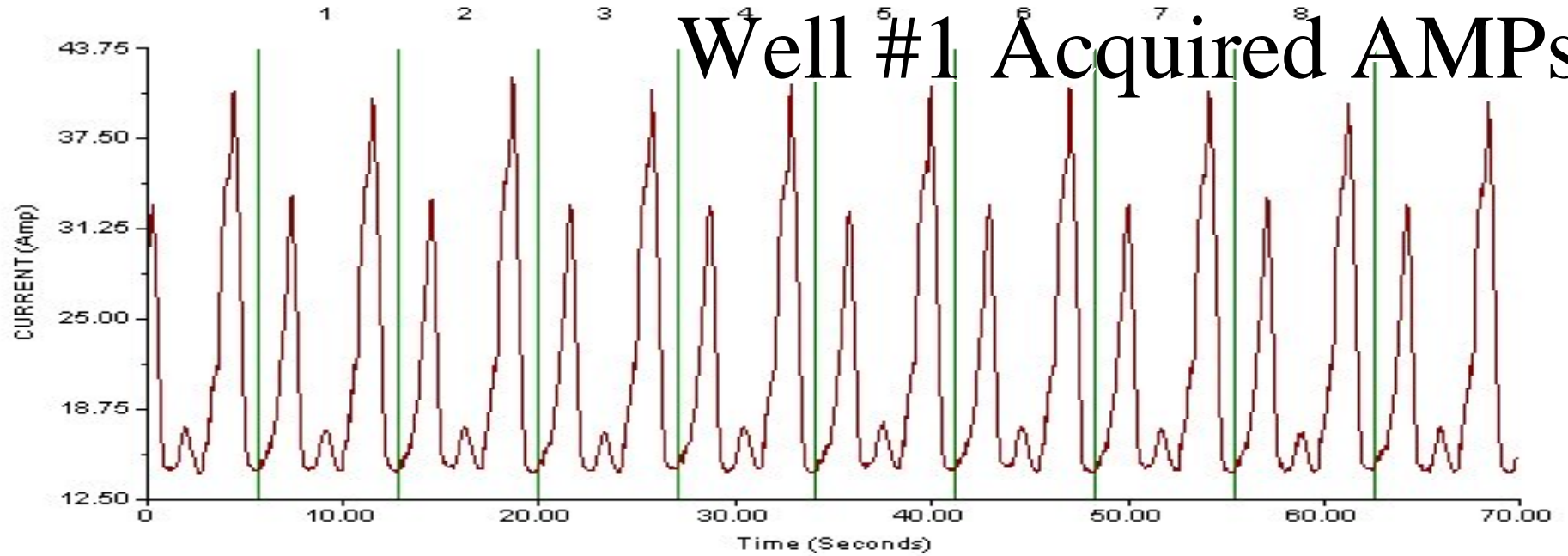
Three Methods Available to Determine Net Gearbox Torque Loading

- 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 counter balance effect, CBE, test.**
- 3) Use surface dynamometer card and torque factors together with counterbalance moments from the crank and weights**

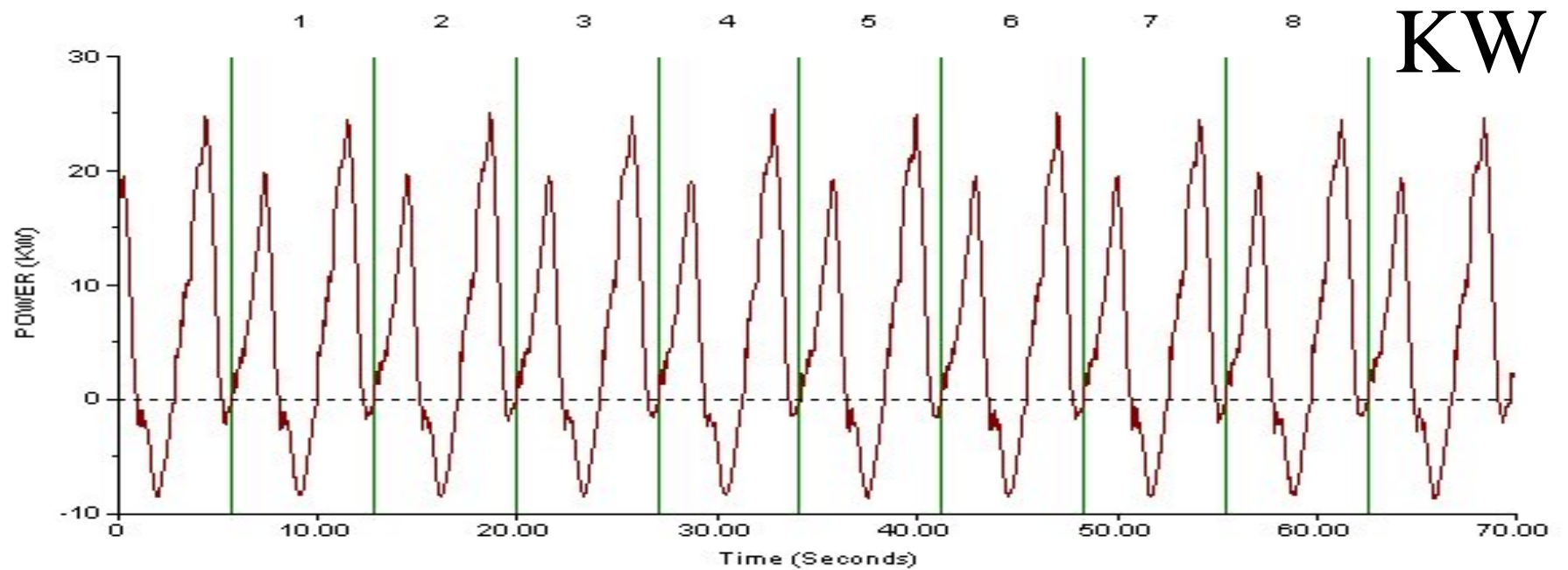
Three Methods to Determine Gearbox Loading



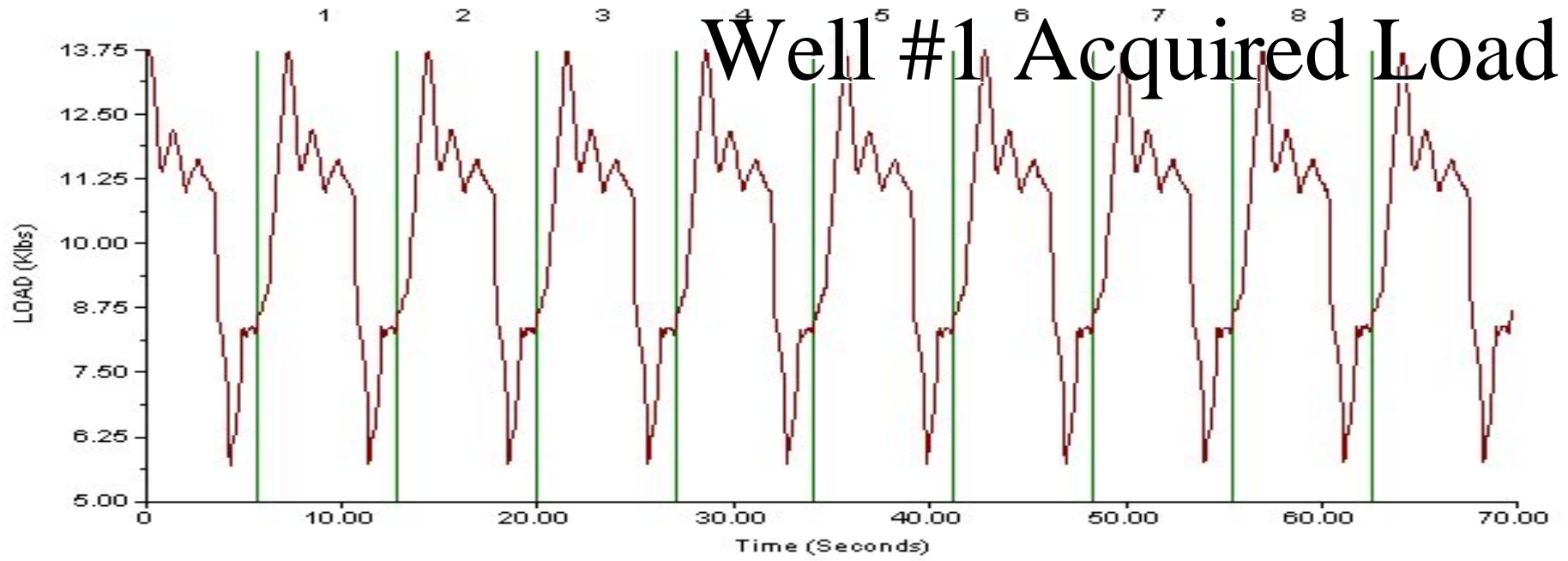
Well #1 Acquired AMPs



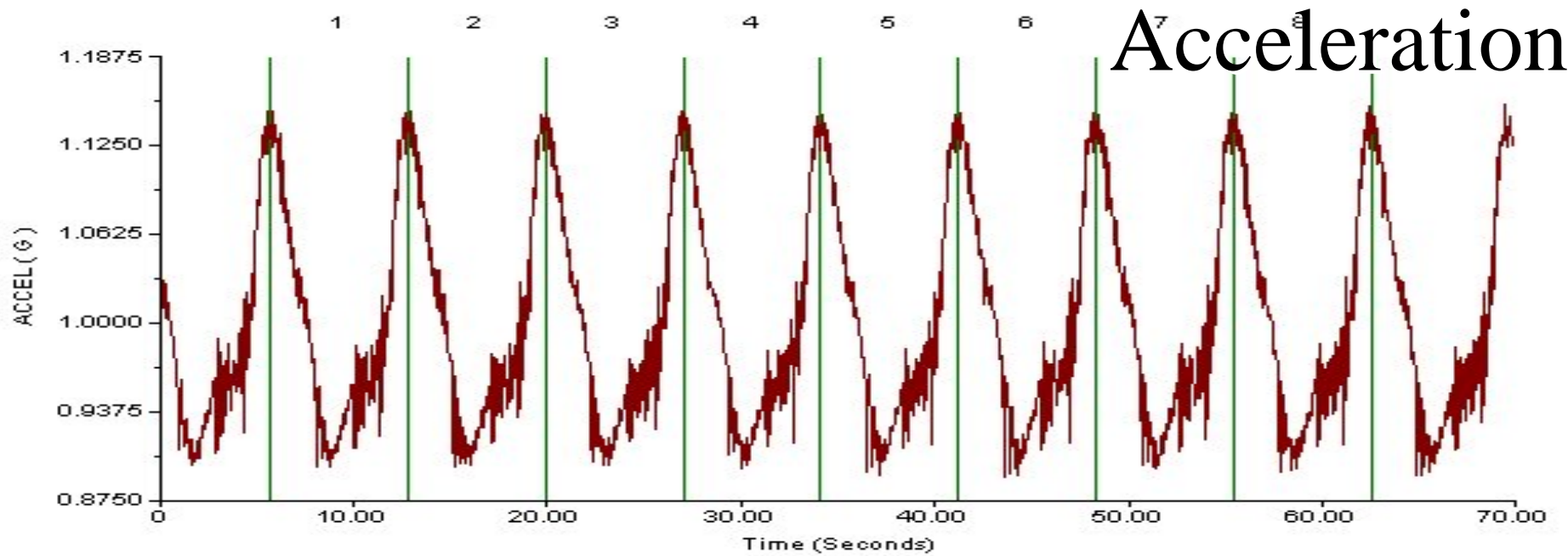
KW



Well #1 Acquired Load



Acceleration

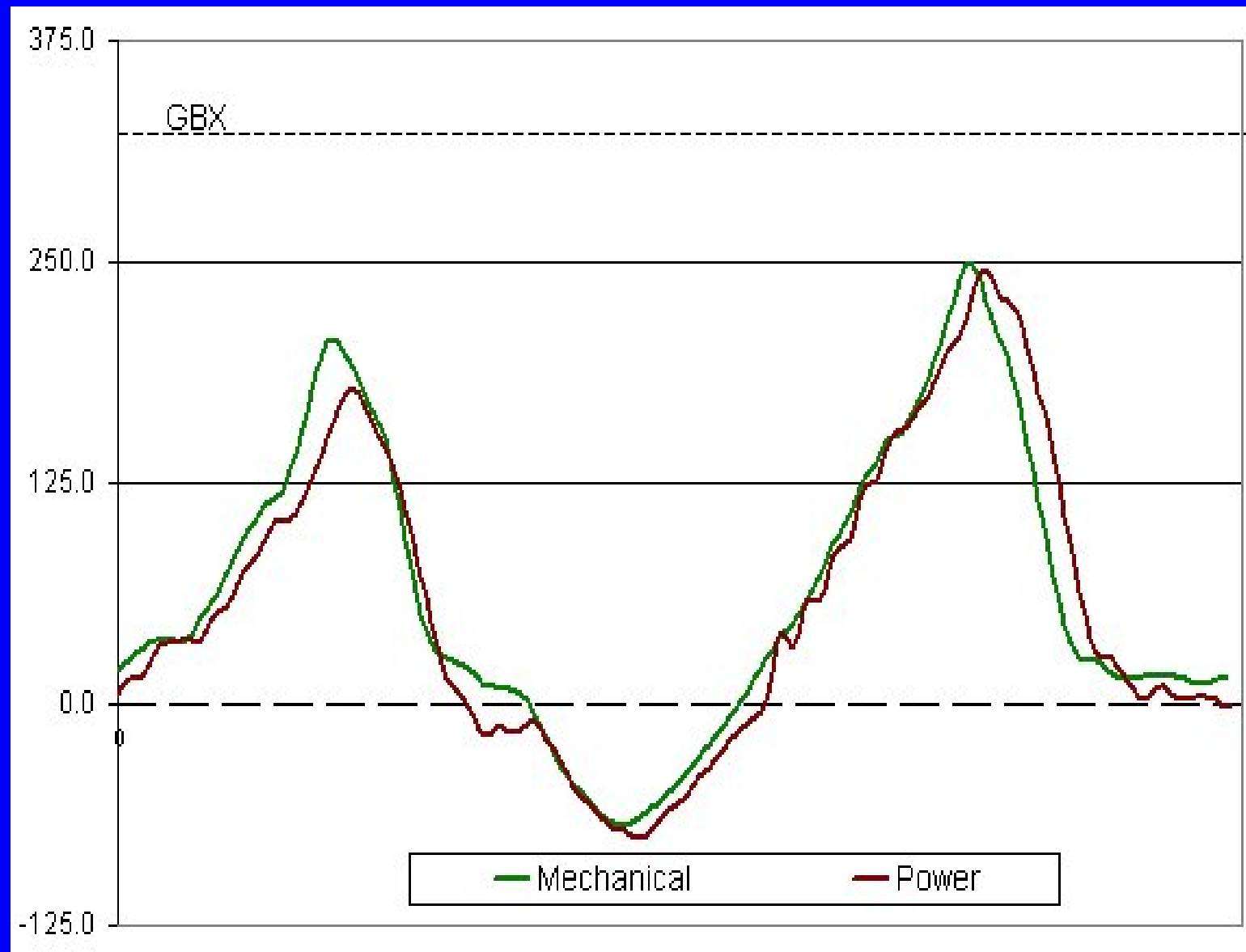


Motor Net Gearbox Torque Behaves Same as Mechanical Net Gearbox Torque

Well #1 Plot of Power and Mechanical Torque Data

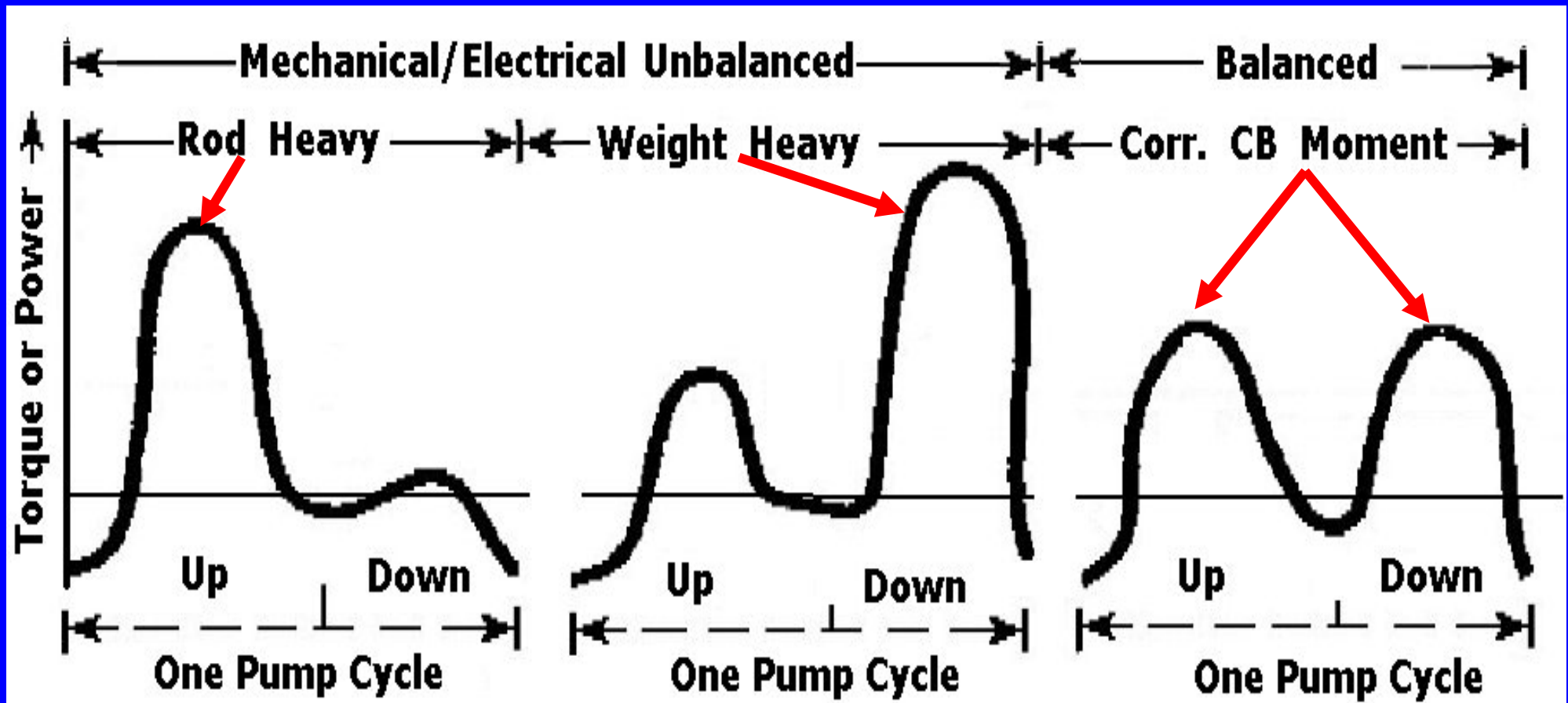
Both show unit weight heavy (overbalanced)

Counterweights need to move in from the end of the crank to balance the peak torques

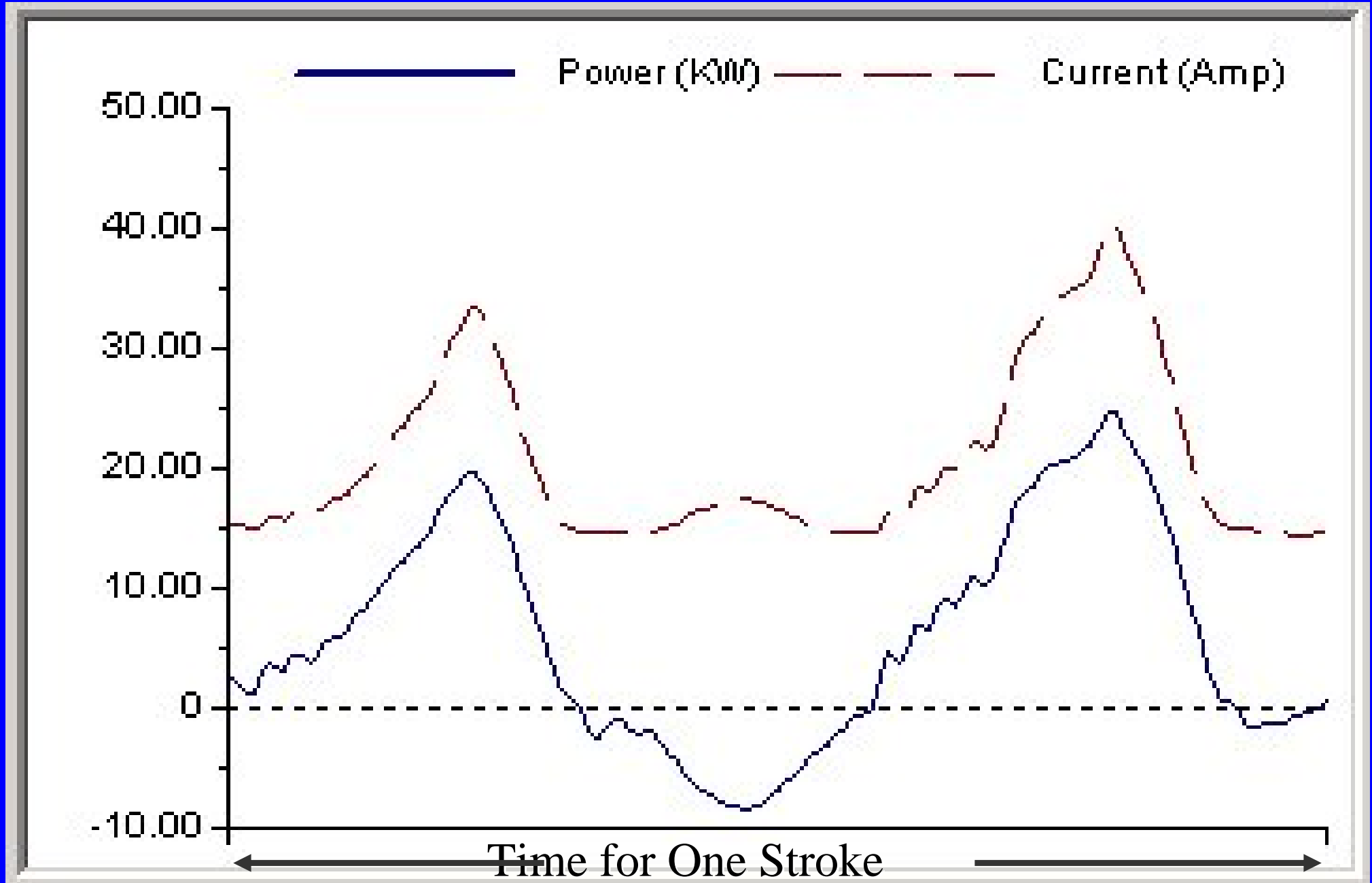


More Uniform Torque Loading Throughout Stroke

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 $T_N = 84.5 \times \text{kW} \times \text{Eff} / (\text{SPM} \times \text{SV})$ to Calculate Net Gearbox Torque

Raw Data | Overlay | Dyna Cards | Torque | Rod Loading | Load/Current | Power Torque | Power F

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

Measured (red solid line) and Balanced Torq. (green dashed line) curves are shown. The graph includes 'BOTTOM', 'TOP', and 'BOTTOM' labels on the x-axis and numerical values on the y-axis.

Torque Analysis		Kin-lb
Measured Upstroke Peak	<input type="text" value="183.7"/>	
Measured Downstroke Peak	<input type="text" value="253.1"/>	
Marker	<input type="text" value="253.1"/>	
Balanced Upstroke Peak	<input type="text" value="217.3"/>	
Balanced Downstroke Peak	<input type="text" value="218.8"/>	
Counter Balance Change For Balanced Torque	<input type="text" value="35.4"/>	

Weight Of Counterweights To Be Moved:
 lb

For Adjusted Torque Move Counterweights:
 IN in

Strokes Per Minute (SPM)

Motor/Belts Efficiency (EFF)

Speed Variation (SV)

Gearbox Rating in-lb

Stroke

Increase

Indicator Movement Control

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**

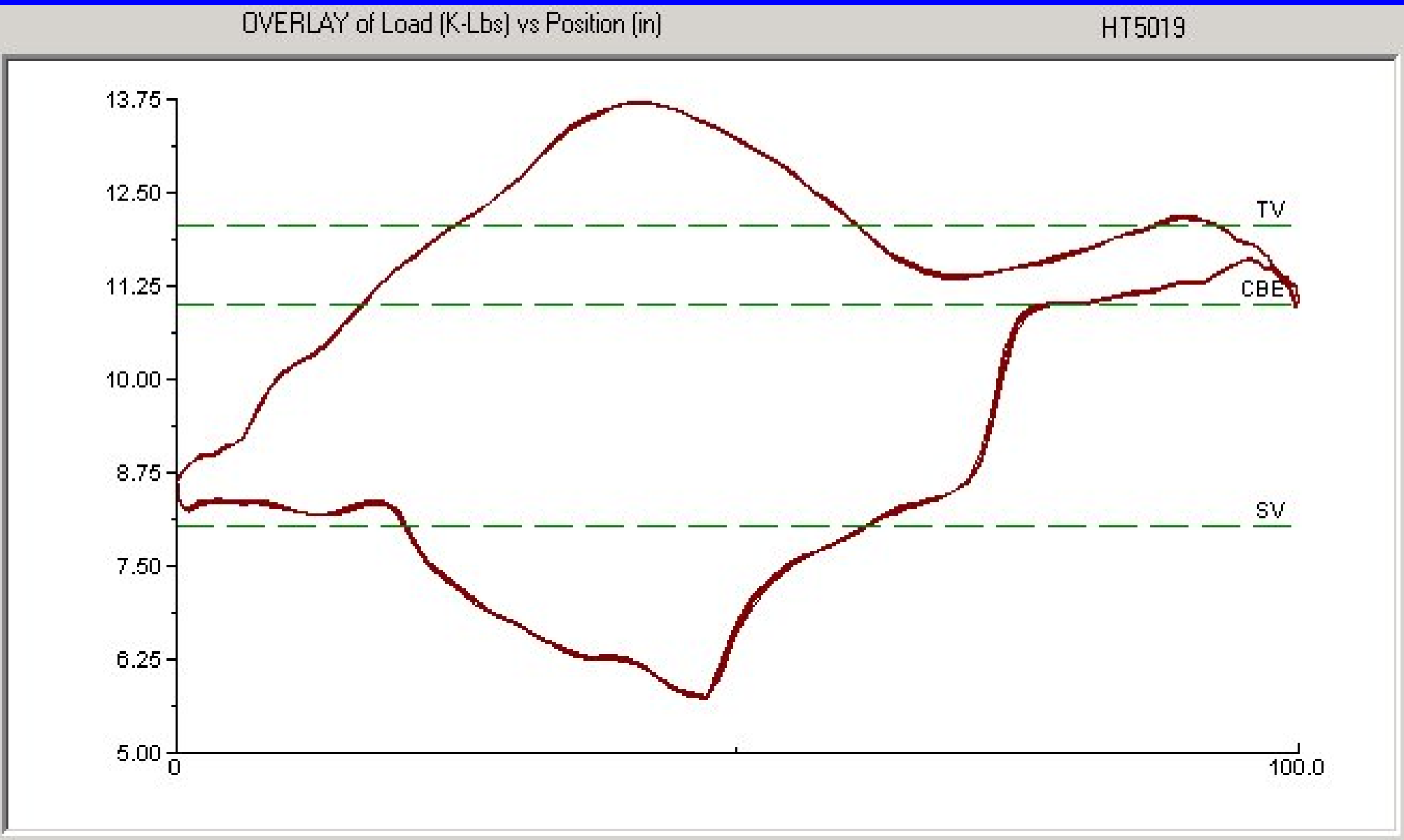
Determine Mechanical Net Gearbox Torque Defined by API Standard 11-E

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 [?] [X]

New Unit Delete Unit Duplicate Unit

Manufacturer: Status: System Unit. Record Locked
Class:
API:

Gearbox	<input type="text" value="320000"/>	in-lb	Structural Load	<input type="text" value="25600"/>	lb			Stroke Length
A	<input type="text" value="129"/>	in	C	<input type="text" value="111"/>	in	R1	<input type="text" value="42"/>	<input type="text" value="100"/>
P	<input type="text" value="132"/>	in	I	<input type="text" value="111"/>	in	R2	<input type="text" value="36"/>	<input type="text" value="85.7143"/>
K	<input type="text" value="175.5"/>	in	Tau	<input type="text" value="0"/>	degree	R3	<input type="text" value="30"/>	<input type="text" value="71.4286"/>
Structural Unbalance	<input type="text" value="550"/>	lb				R4	<input type="text" value="24"/>	<input type="text" value="57.1429"/>
						R5	<input type="text"/>	<input type="text"/>
Comment	<input type="text"/>					R6	<input type="text"/>	<input type="text"/>

Done Save Diagram

Torque Factors Derived from Geometry of Selected Pumping Unit

Pumping Unit Library

Lufkin Conventional
Conventional
C-320D-256-100

A	<input type="text" value="129"/>	in
P	<input type="text" value="132"/>	in
C	<input type="text" value="111"/>	in
I	<input type="text" value="111"/>	in
K	<input type="text" value="175.5"/>	in
R1	<input type="text" value="42"/>	in
R2	<input type="text" value="36"/>	in
R3	<input type="text" value="30"/>	in
R4	<input type="text" value="24"/>	in
R5	<input type="text"/>	in
R6	<input type="text"/>	in

The diagram illustrates the geometry of a pumping unit. It shows a horizontal beam pivoted at its center. A counterweight is attached to the right end of the beam, and a pumpjack is attached to the left end. The diagram labels several dimensions: A (beam length from pivot to counterweight), P (beam length from pivot to pumpjack), C (beam length from pivot to a specific point), I (total beam length), K (distance from pivot to the center of the counterweight), and R (radius of the counterweight). A counter-clockwise torque T_{WN} is shown at the pivot, and a downward weight W_N is shown at the counterweight. A dashed line indicates the path of the counterweight's center of mass.

OK

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 = well load at a specific crank angle

SU = structural unbalance of the pumping unit
(either plus or minus value)

TF = torque factor, inches

Counterbalance Moment, M_e , from CBE

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

Where:

M_e = 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

θ = the crank angle (90)

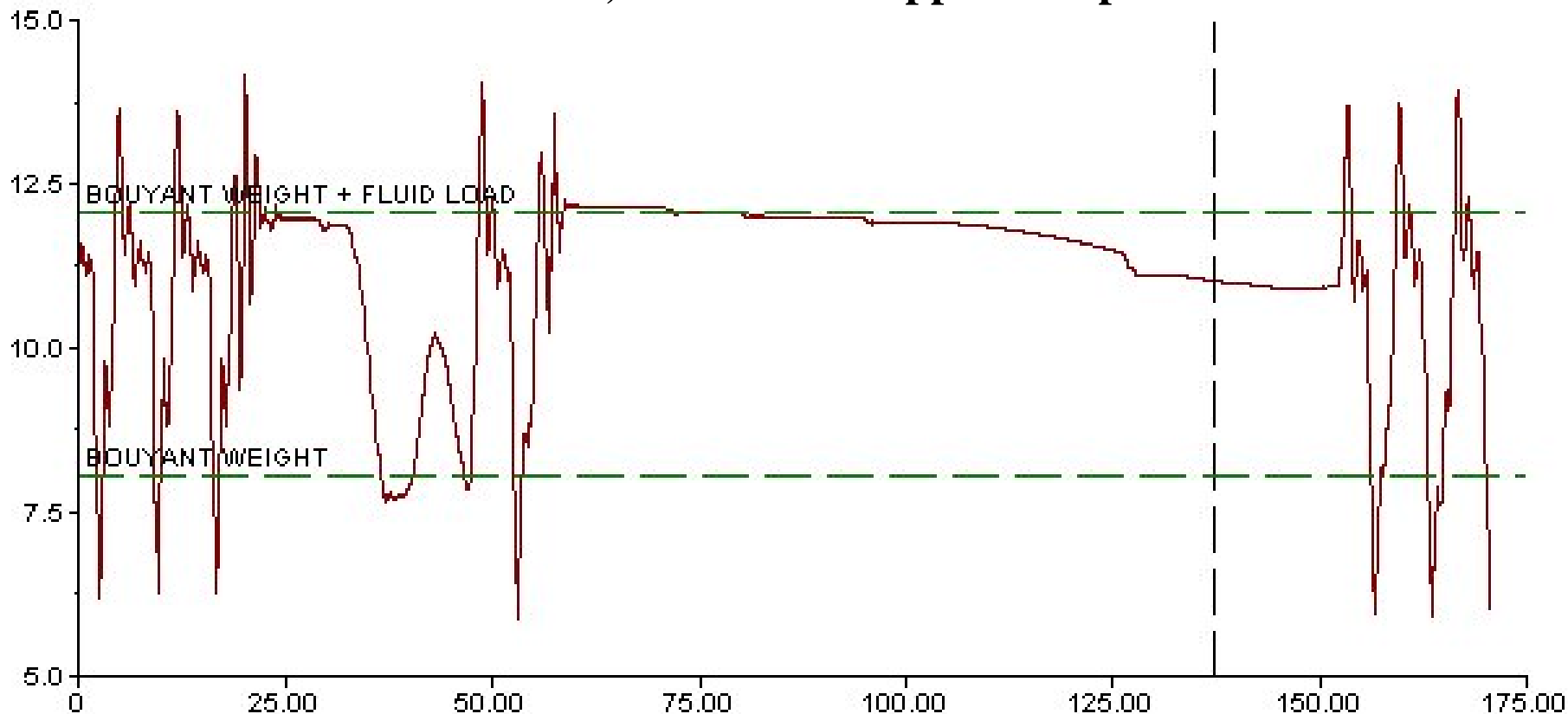
τ = the crank phase angle

Field Measured CBE with Crank Level

Example Well #1

CBE Load (K-Lbs) vs Time (sec)

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



@ 137.2 sec

Counter Balance Effect Load 11024.6 lbf

Indicator Movement Control

Calculated Bouyant Rod Weight 8040.76 lbf

← Left

Right →



Calculated Bouyant Rod Weight + Fluid Load 12062.1 lbf

Determine Mechanical Net Gearbox Torque Defined by API Standard 11-E

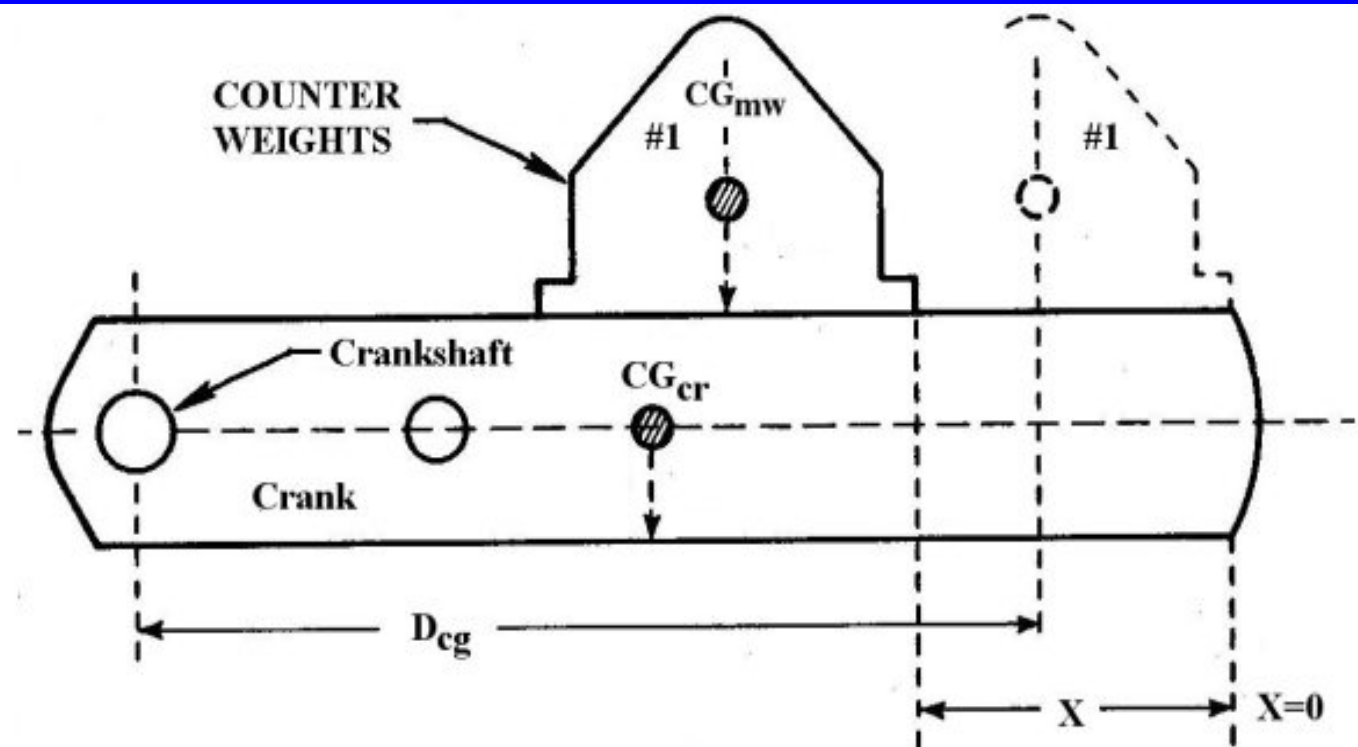
Torque Factor Method is the Standard Method to Determine the Instantaneous Torque Throughout the Pumping Cycle

Use:

- **Polished Rod Load and Position Data**
- **Torque Factors**
- **Together with Counterbalance Moments**

Calculate Counterbalance Moment for Conventional Pumping Units with Crank Mounted Counterweights

$$M_e = M_{cr} + \sum_{i=1}^{N_m} W_m \times (D_{cg} - X_i) + \sum_{i=1}^{N_a} W_a \times (D_{cg} - X_i)$$



Note:

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

Where:

- M_e = Existing counterbalance moment of the crank and counter weights (in-lbs)
- M_{cr} = Crank counterbalance moment (in-lbs)
- W_{m_i} = Weight of the master counterweight (lbs)
- W_{a_i} = Weight of the auxiliary counterweight (lbs)
- D_{cg_i} = Maximum distance from centerline of the Crankshaft to the counterweight center of gravity (in)
- X_i = Distance from end of the crank to the outside edge of the counterweight
- X_{max} = Maximum distance along crank that counterweight can be moved
- N_m = Number of master counterweights
- N_a = Number of auxiliary counterweights

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):

	Crank #1	Crank #2
Name	8495B	8495B
Weight - Lbs	3510	3510
Center Gravity (CG) - inches	46.25	46.25
Mcr, Crank Moment (in-lbs):	162,338	162,338

	Master Weight		Master Weight	
	#1	#2	#1	#2
Name	3CRO	3CRO	3CRO	3CRO
Wmi, Weight (Lbs)	1327	1327	1327	1327
Dcgi (inches)	72.2	72.2	72.2	72.2
Xi. (inches)	40	40	40	40
CG - inches	32.2	32.2	32.2	32.2
M. W. Moment (in-lbs):	44,056	44,056	44,056	44,056

Total Moment: $2 \times 162,338 + 4 \times 44,056 = 500,900$ 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

Currently Selected Unit

Manufacturer: Lufkin Unit Class: Conventional

API Description: C-320D-256-100 Unit Description: C-320D-256-100

CRANK #1

Crank No.: 8495B

Master Weight #1

Master Wt. No.: 3CRO

Aux .1 Wt. No.: NONE

Aux .2 Wt. No.: NONE

Distance From End of Crank: 40 in

Master Weight #2

Master Wt. No.: 3CRO

Aux .1 Wt. No.: NONE

Aux .2 Wt. No.: NONE

Distance From End of Crank: 40 in

CRANK #2

Crank No.: 8495B

Master Weight #1

Master Wt. No.: 3CRO

Aux .1 Wt. No.: NONE

Aux .2 Wt. No.: NONE

Distance From End of Crank: 40 in

Master Weight #2

Master Wt. No.: 3CRO

Aux .1 Wt. No.: NONE

Aux .2 Wt. No.: NONE

Distance From End of Crank: 40 in

Weight of Counter Weights: 5308 lb

Counter Balance Moment Existing: 500901 in-lb

Done

Torque due to Counterbalance Moment CBE or CBM

$$T_{CN} = M x \sin (\theta + \tau)$$

Where:

**M = existing counterbalance moment of the
crank and counter weights**

θ = the crank angle

τ = 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:

$$T_N = TF \times W_N - M \times \sin(\theta + \tau)$$

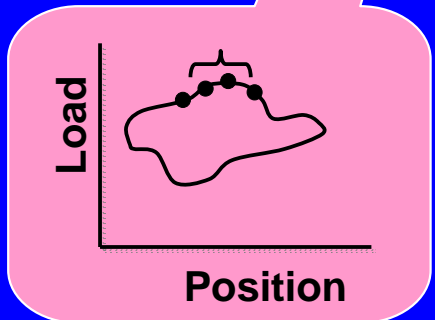
Net Gearbox Torque, T_N

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

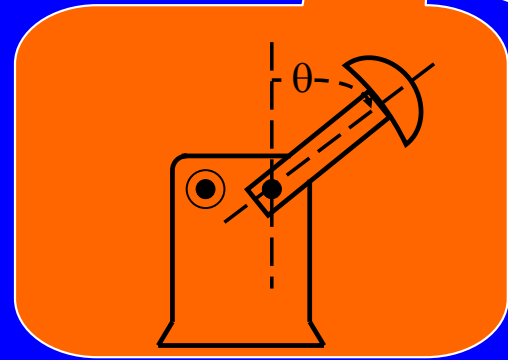
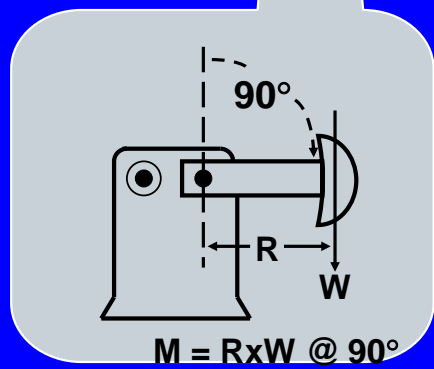
- T_N = net gearbox torque (inch-lbs)
- TF = torque factor at crank angle θ ,
(in-lbs)/lbs = inch
- W = polished rod load at θ , (lbs)
- SU = structural unbalance of unit (if negative, head falls, lbs)
- M = maximum counter weight moment (in-lbs)
- θ = crank angle (degrees)
- τ = crank offset angle (degrees)

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

Torque Factor:
From tables or
calculated,
(in-lbf)/lbf, each
load & position



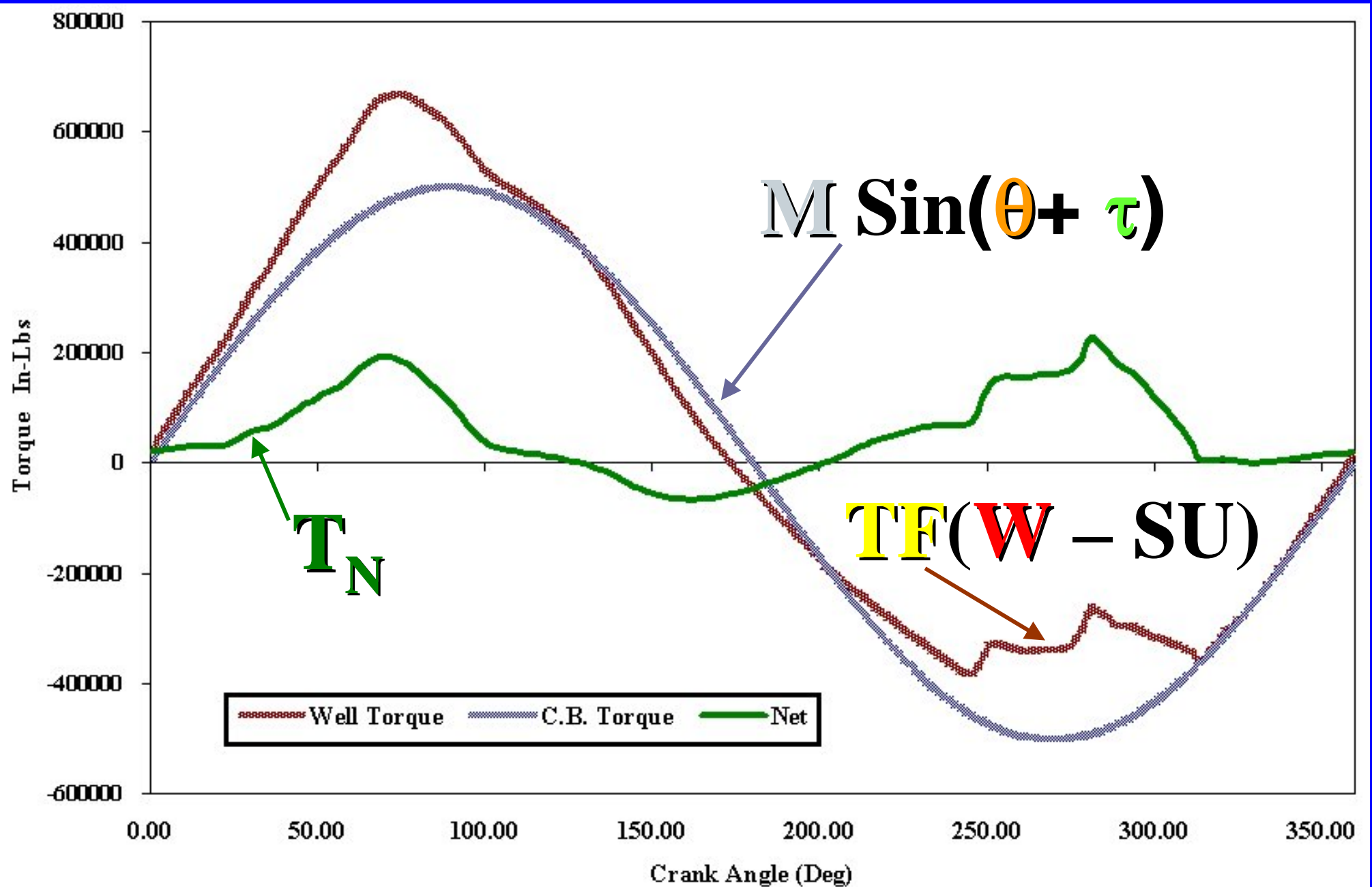
**Structural
unbalance, Lbf,
if negative,
head falls**



Example of API Standard 11-E Calculations

(1) Crank Angle Deg	(2) Phase Angle Deg	(3) Col1 + Col2 Deg	(4) Sin(Col3)	(5) Well Load (Lbs)	(6) Structural Unbalance (Lbs)	(7) Col 5-6 Net PRL (Lbs)	(8) Torque Factor (In)	(9) Col 7x8 Well Torque (In-Lbs)	(10) C.B. Moment (In-Lbs)	(11) Col 4x10 C.B. Torque (In-Lbs)	(12) Col 9-11 Net Torque (In-Lbs)
0.0	0	0.00	0.000	8658	550	8108	1.58	12794	500900	0	12794
15.0	0	15.00	0.259	9005	550	8455	18.87	159565	500900	129642	29922
30.0	0	30.00	0.500	10107	550	9557	32.11	306898	500900	250450	56448
45.0	0	45.00	0.707	11423	550	10873	41.87	455190	500900	354190	101001
60.0	0	60.00	0.866	12767	550	12217	48.17	588525	500900	433792	154733
75.0	0	75.00	0.966	13636	550	13086	51.14	669253	500900	483832	185421
90.0	0	90.00	1.000	12485	550	11935	50.76	605893	500900	500900	104993
105.0	0	105.00	0.966	11408	550	10858	46.91	509394	500900	483832	25562
120.0	0	120.00	0.866	11774	550	11224	39.59	444325	500900	433792	10533
135.0	0	135.00	0.707	12189	550	11639	29.35	341568	500900	354190	-12622
150.0	0	150.00	0.500	11761	550	11211	17.59	197159	500900	250450	-53291
165.0	0	165.00	0.259	11113	550	10563	6.01	63476	500900	129642	-66167
173.5	0	173.50	0.113	11131	550	10581	0.00	0	500900	56704	-56704
180.0	0	180.00	0.000	11260	550	10710	-4.28	-45869	500900	0	-45869
195.0	0	195.00	-0.259	11504	550	10954	-13.12	-143701	500900	-129642	-14058
210.0	0	210.00	-0.500	11433	550	10883	-20.87	-227123	500900	-250450	23327
225.0	0	225.00	-0.707	11203	550	10653	-28.04	-298702	500900	-354190	55488
240.0	0	240.00	-0.866	11033	550	10483	-34.96	-366499	500900	-433792	67293
255.0	0	255.00	-0.966	8449	550	7899	-41.64	-328890	500900	-483832	154942
270.0	0	270.00	-1.000	7689	550	7139	-47.52	-339252	500900	-500900	161648
285.0	0	285.00	-0.966	5914	550	5364	-55.48	-297574	500900	-483832	186258
300.0	0	300.00	-0.866	6706	550	6156	-50.99	-313910	500900	-433792	119882
315.0	0	315.00	-0.707	8364	550	7814	-44.72	-349428	500900	-354190	4761
330.0	0	330.00	-0.500	8344	550	7794	-32.18	-250796	500900	-250450	-346
345.0	0	345.00	-0.259	8302	550	7752	-15.34	-118904	500900	-129643	10738
357.8	0	357.80	-0.038	8651	550	8101	0.00	0	500900	-19229	19229
360.0	0	360.00	0.000	8658	550	8108	1.58	12794	500900	0	12794

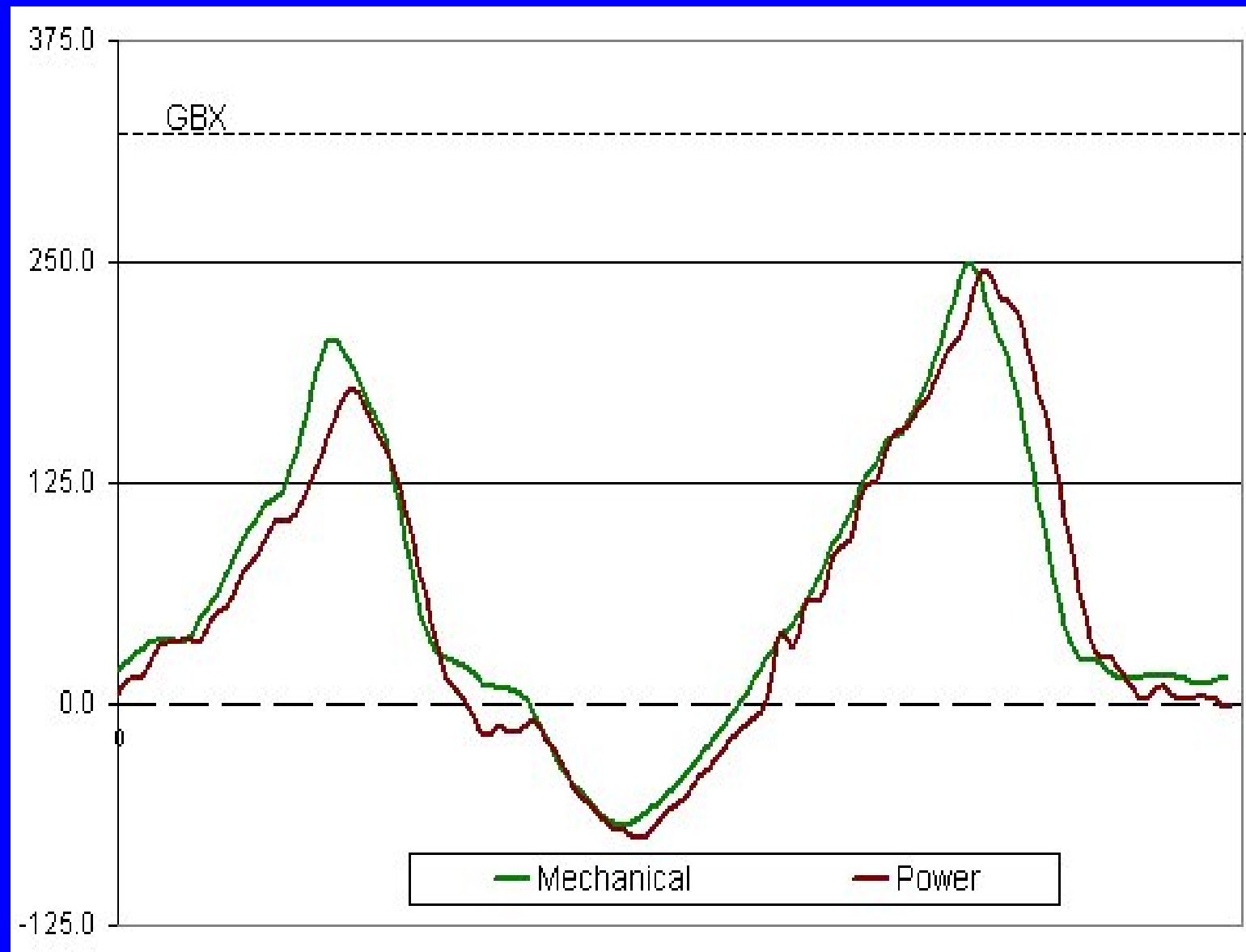
Plot of API Standard 11-E Calculations



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 ($T_{Nd} = T_{Nu}$).

$$M = [TF_d \times (W_d - SU) - TF_u \times (W_u - SU)] / [\sin(\theta_d + \tau) - \sin(\theta_u + \tau)]$$

Select Mechanical Torque Method

File Mgmt

General

Surface Equip.

Wellbore

Conditions

Press. Transient Data

[Alt-1] Surface Unit

Manufacturer Lufkin Conventional

Unit Class Conventional

API C-320D-256-100

Stroke Length 100 in

Rotation CW CCW

For Net Torque Calculations Use:

Counter Balance Effect (Weights level)

11.0246 Klb

CBM

Counter Balance Moment (Existing)

500.9 Kin-lb

Counter Weights...

Weight Of Counter Weights 5324 lb

File Mgmt

General

Surface Equip.

Wellbore

Conditions

Press. Transient Data

[Alt-1] Surface Unit

Manufacturer Lufkin Conventional

Unit Class Conventional

API C-320D-256-100

Stroke Length 100 in

Rotation CW CCW

For Net Torque Calculations Use:

Counter Balance Effect (Weights level)

11.0246 Klb

CBE

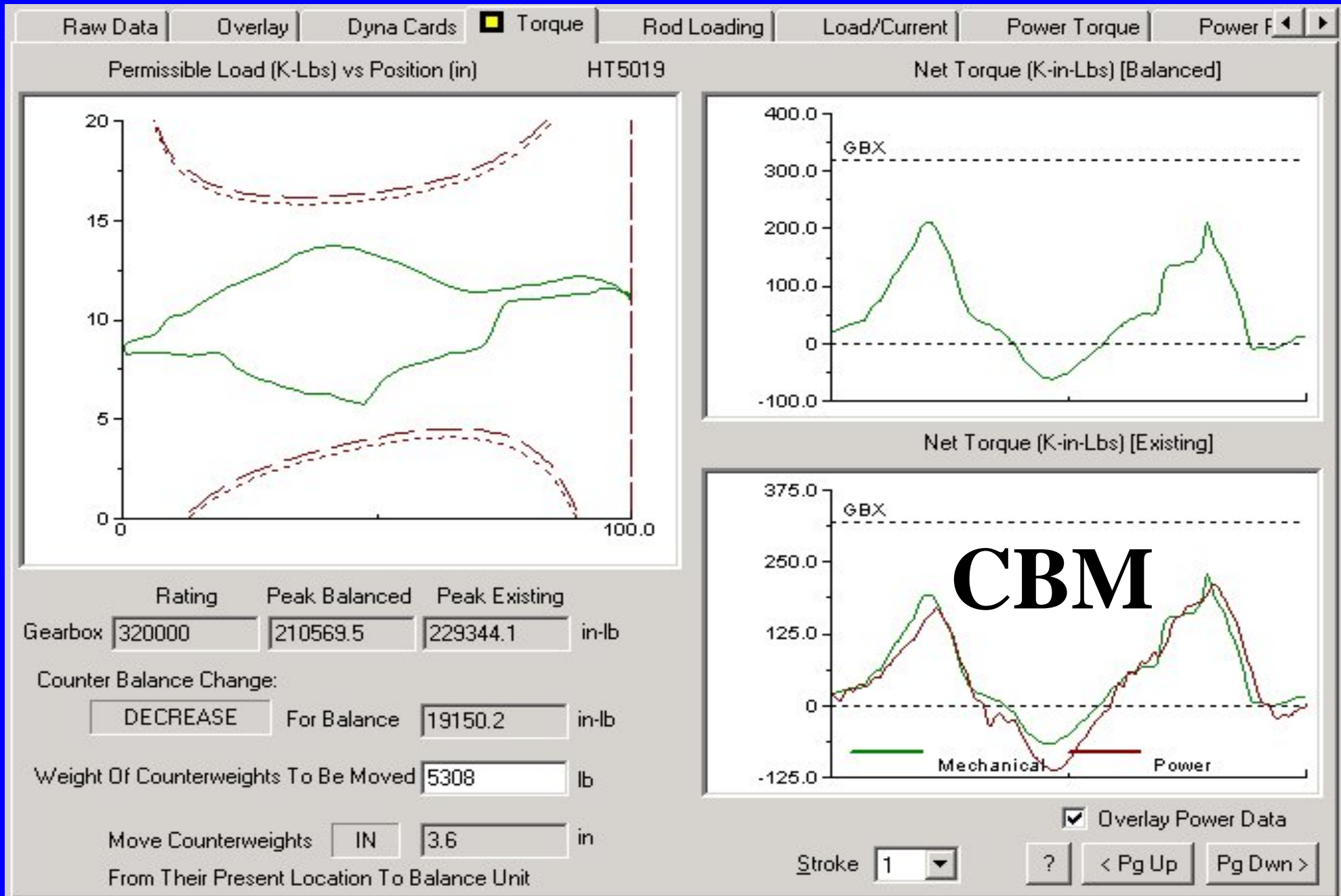
Counter Balance Moment (Existing)

500.9 Kin-lb

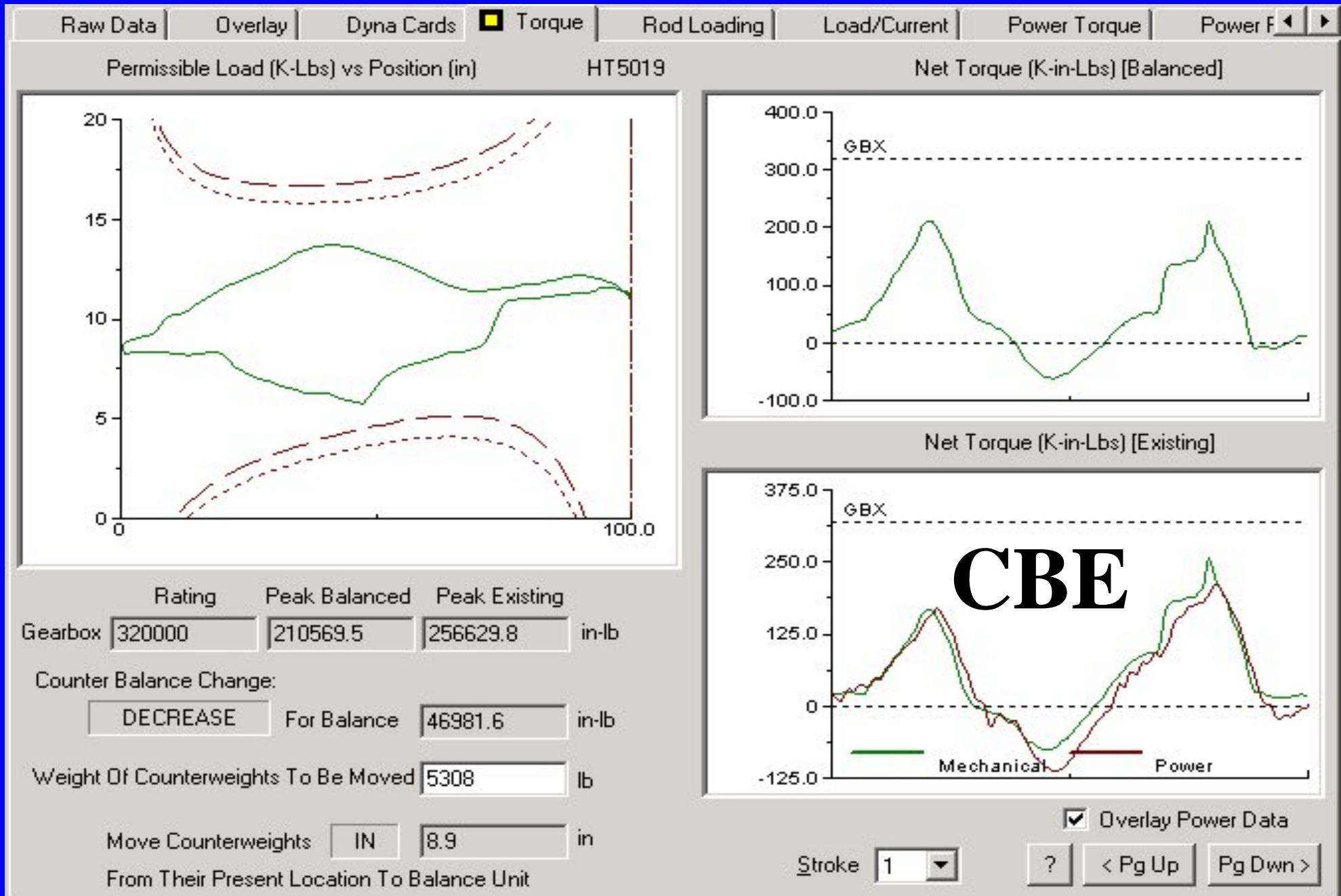
Counter Weights...

Weight Of Counter Weights 5324 lb

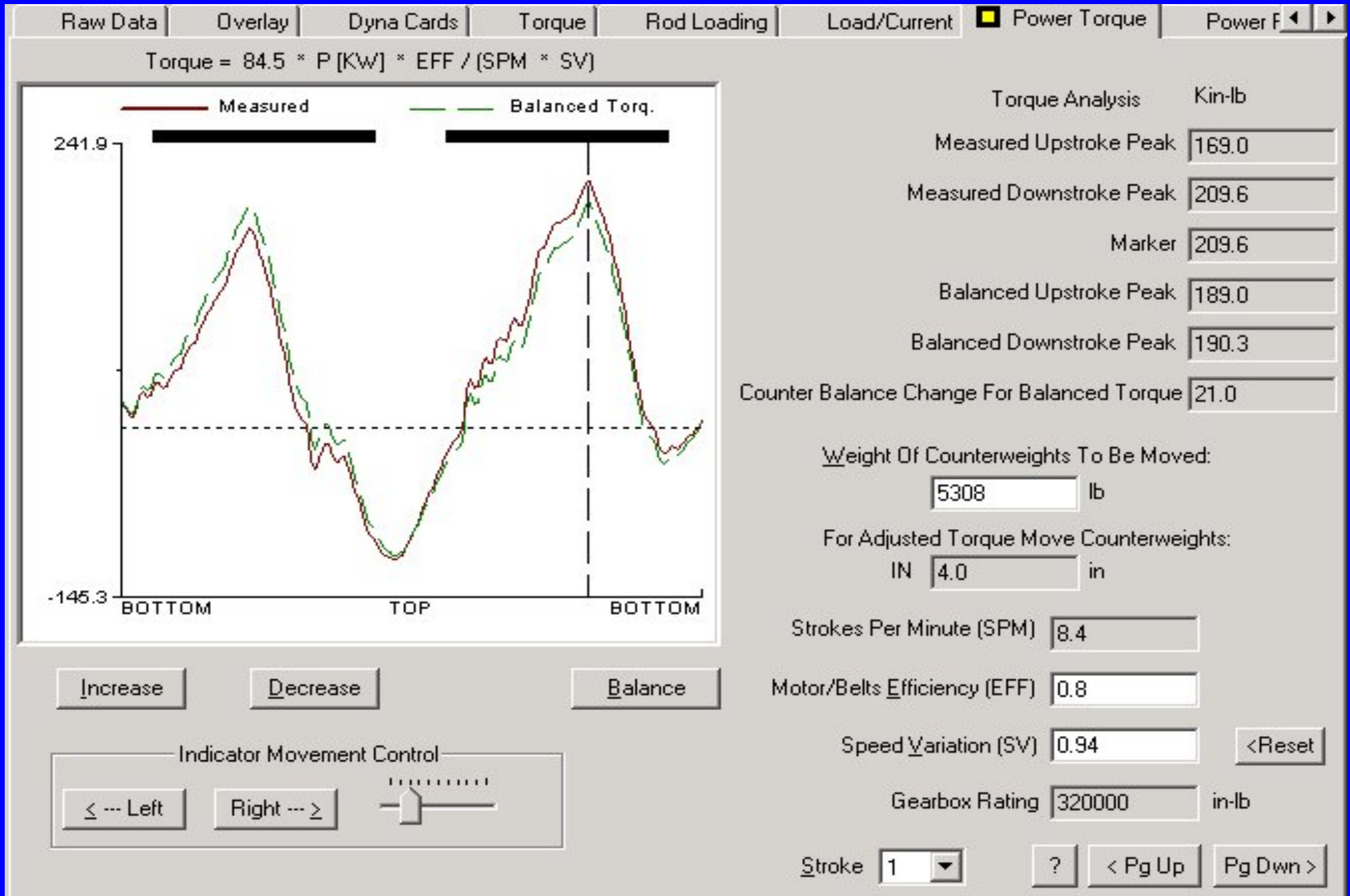
Net Gearbox Torque - Mechanical



Net Gearbox Torque - Mechanical



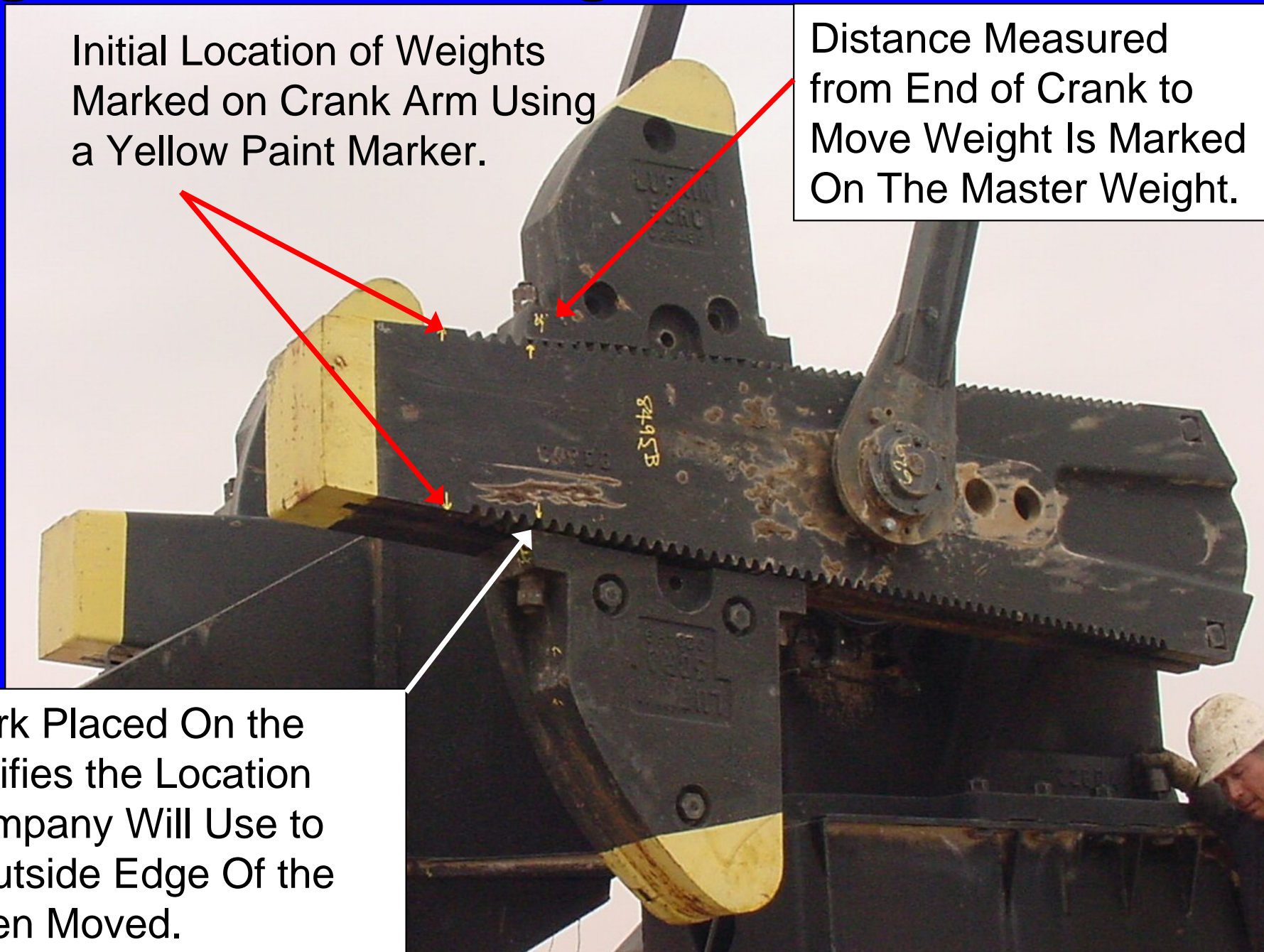
Net Gearbox Torque - Power



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.

Questions ?

