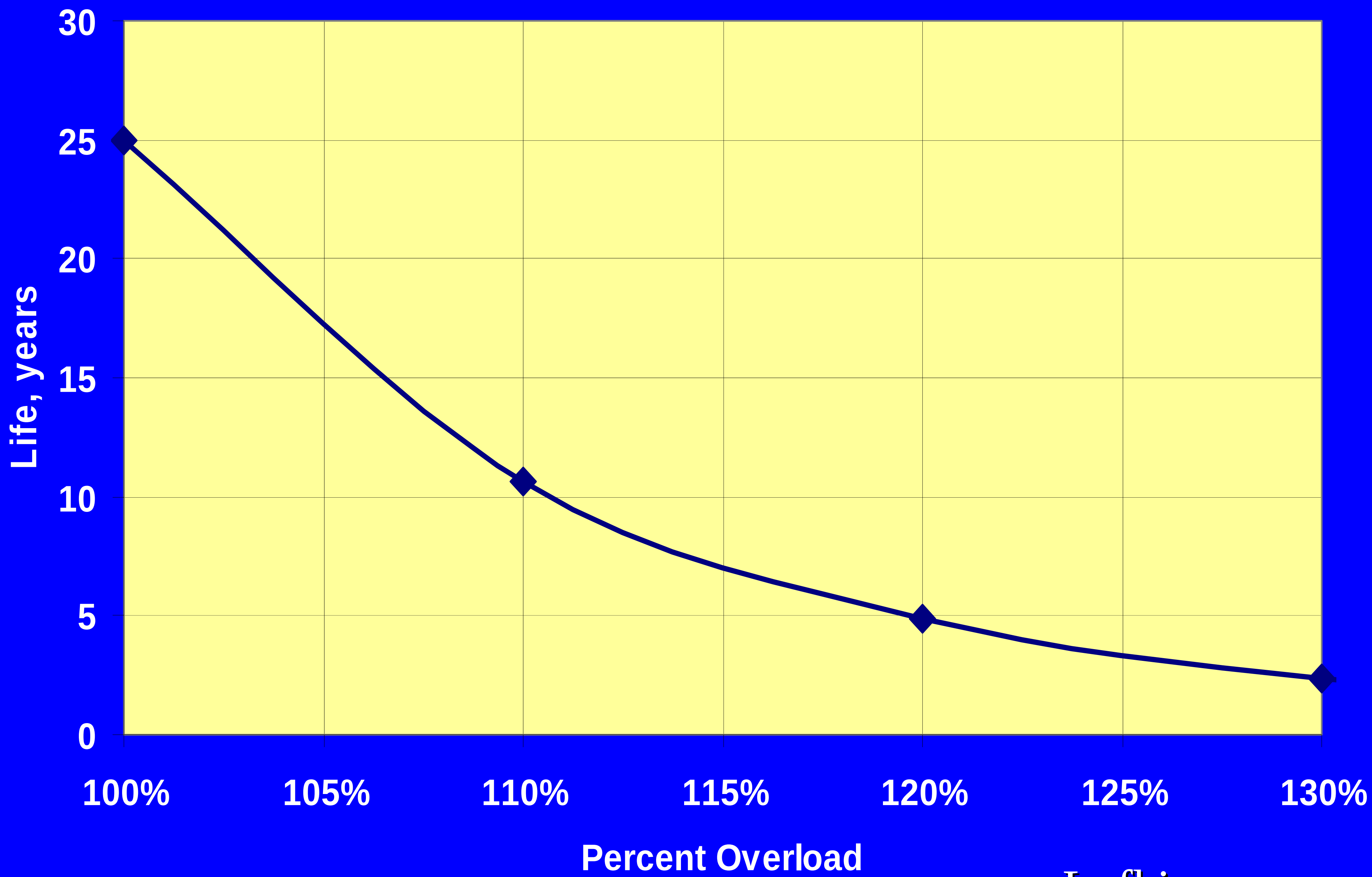
Best Method to Balance Net Torque Loading on a Pumping Unit Gearbox

Reduced Gear Life Relative to % Overload



Lufkin

Reasons to Properly Counter Balance Gearbox Loading

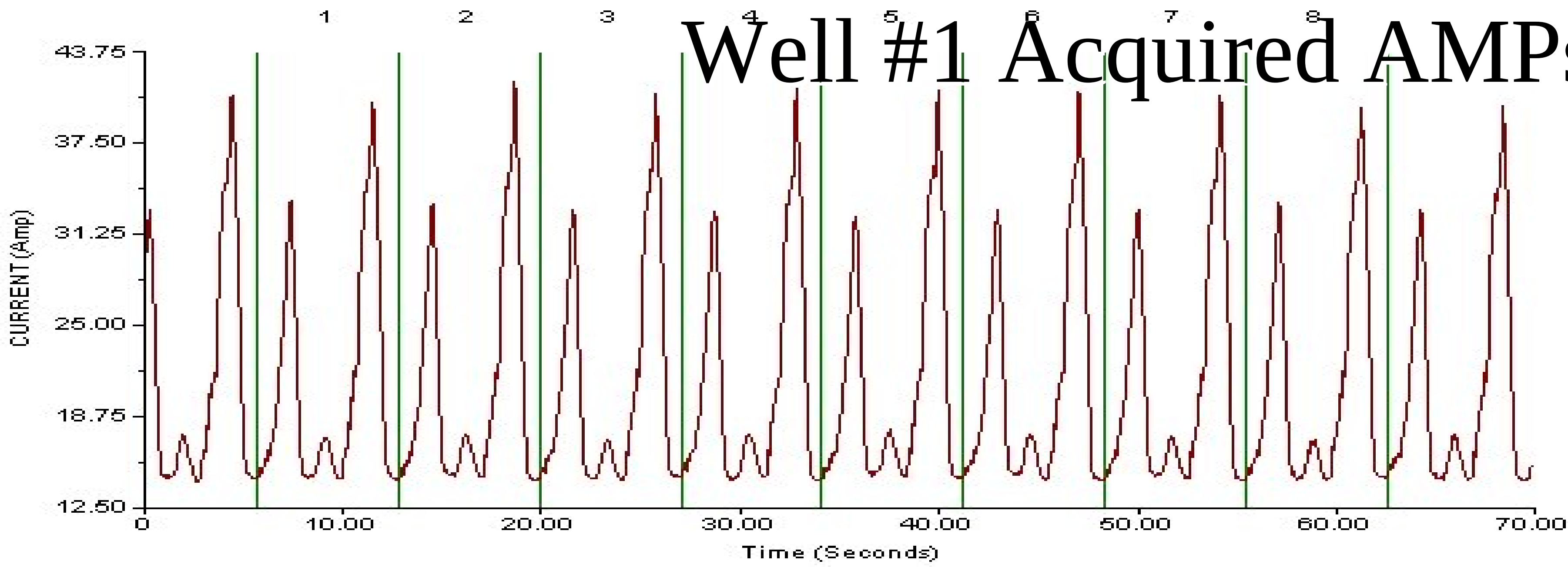
1) Reduce Operating Expenses
2) Minimize Torque Loading on Gearbox and Not Exceed Gearbox Load Rating
3) More Uniform Torque Loading through out Stroke
4) Minimize Energy Cost
5) Minimize Prime Mover Requirements
6) Do not Damage Artificial Lift Equipment

Three Methods Available to Determine Net Gearbox Torque Loading

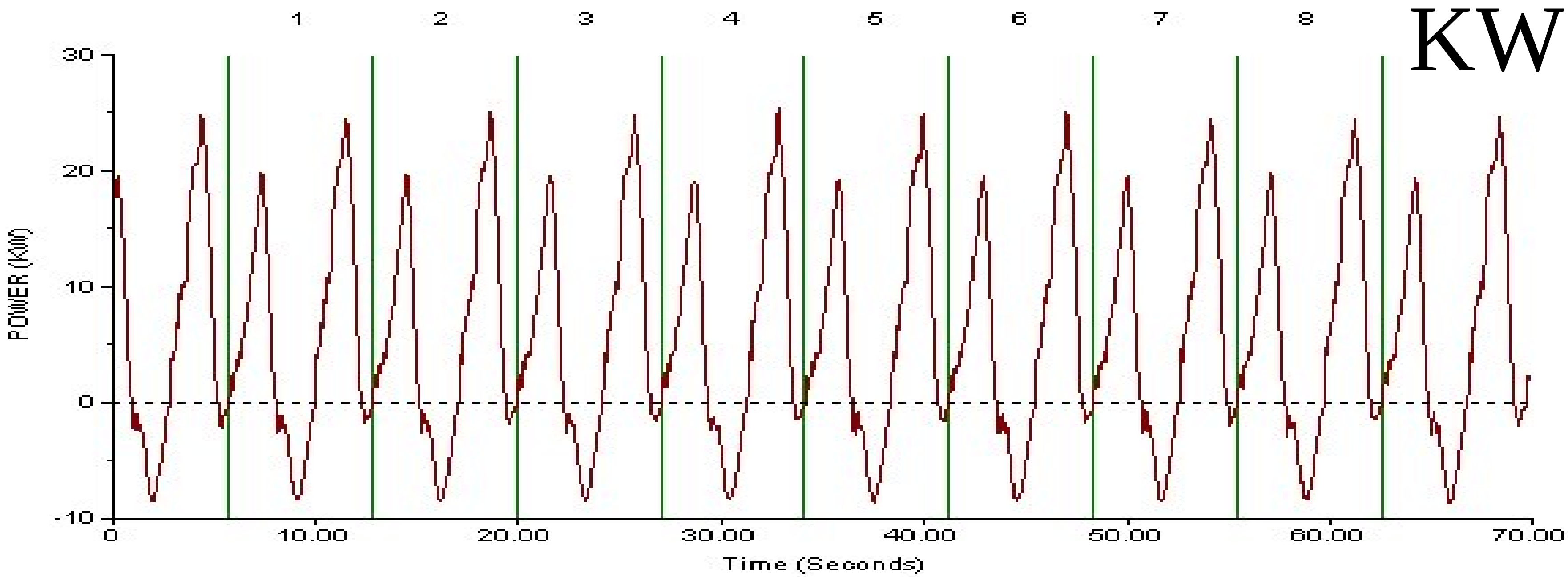
1) Use Input Motor Power, motor and drive efficiencies and the pumping unit speed
2) Use surface dynamometer card and torque factors together with counterbalance moments determined from static counter balance effect, CBE, test.
3) Use surface dynamometer card and torque factors together with counterbalance moments from the crank and weights

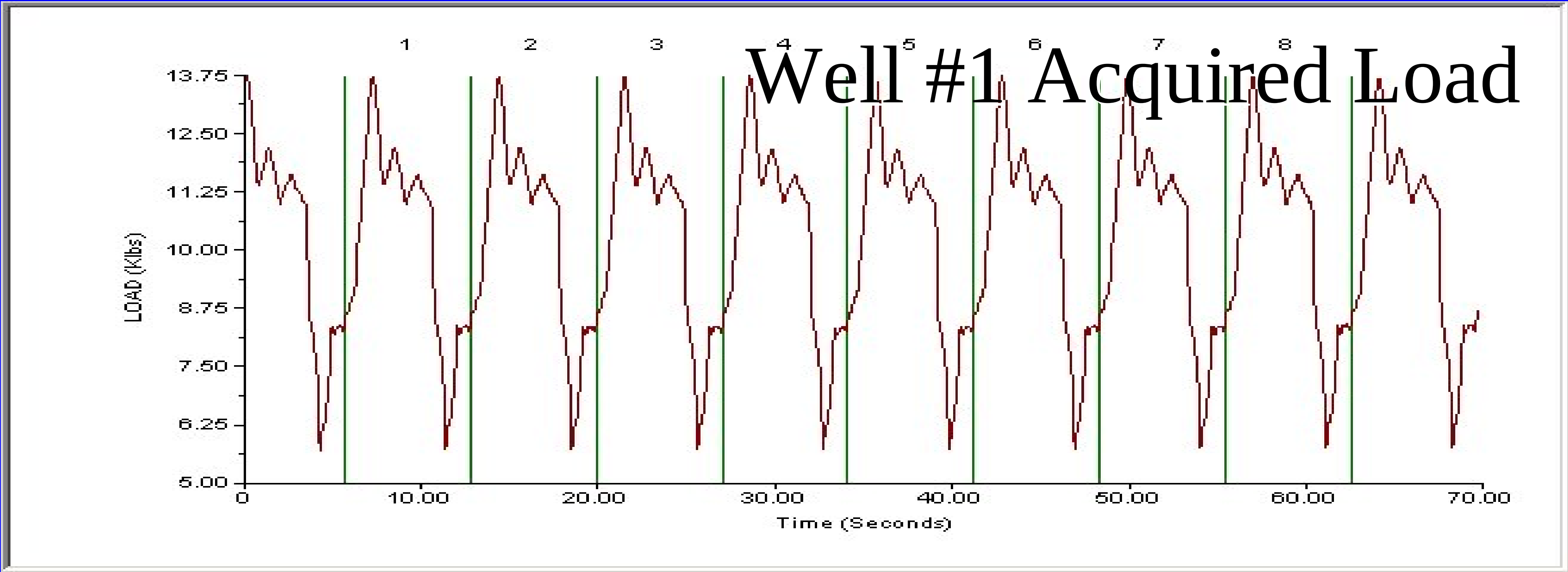
Three Methods to Determine Gearbox Loading

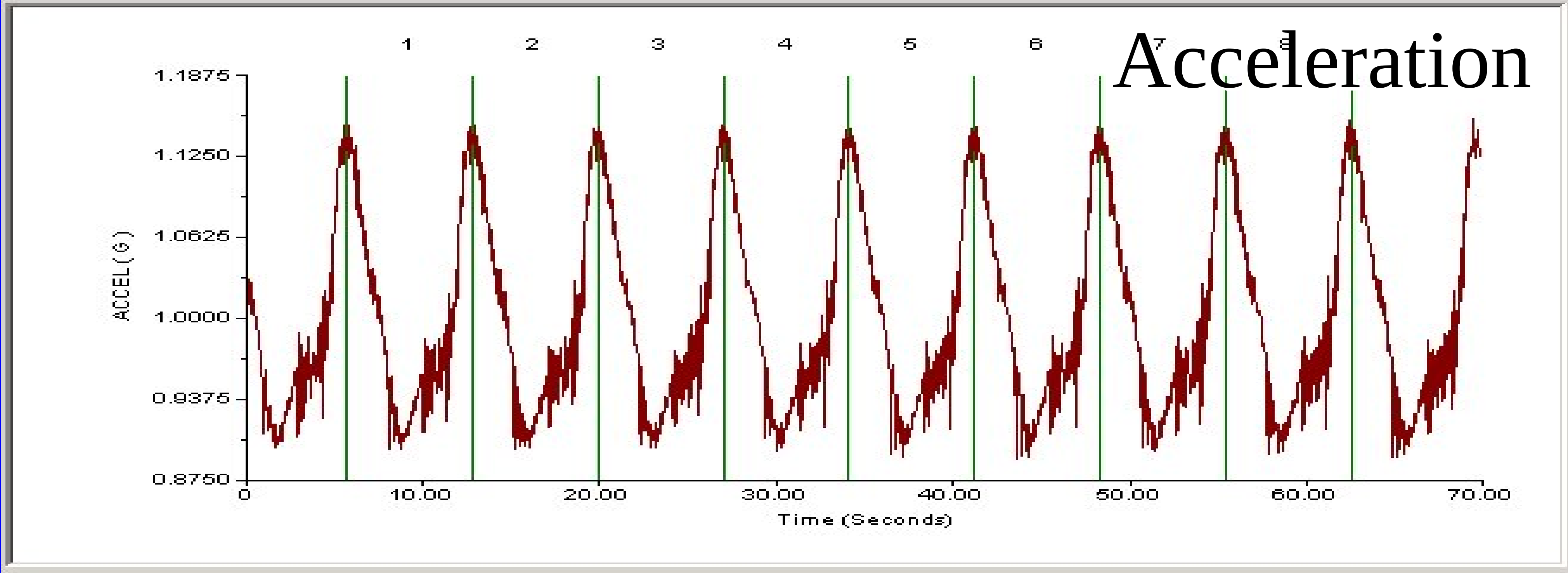
Well #1 Acquired AMPs



KW




Well #1 Acquired Load
LOAD (Klbs)
Time (Seconds)
1
2
3
4
5
6
7
8

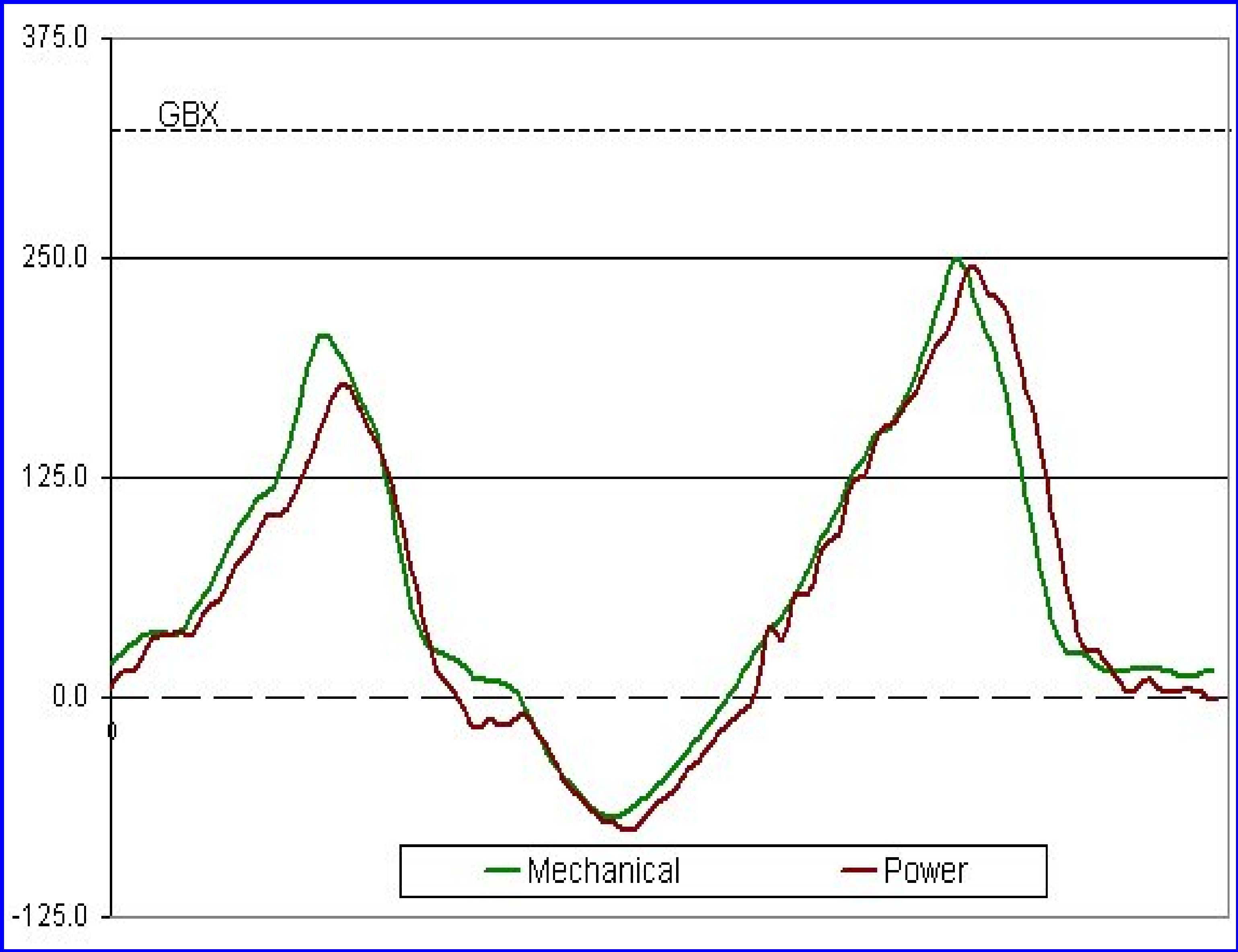

Acceleration
ACCEL (G)
Time (Seconds)
1
2
3
4
5
6
7
8

Motor Net Gearbox Torque Behaves Same as Mechanical Net Gearbox Torque

Well #1 Plot of Power and Mechanical Torque Data

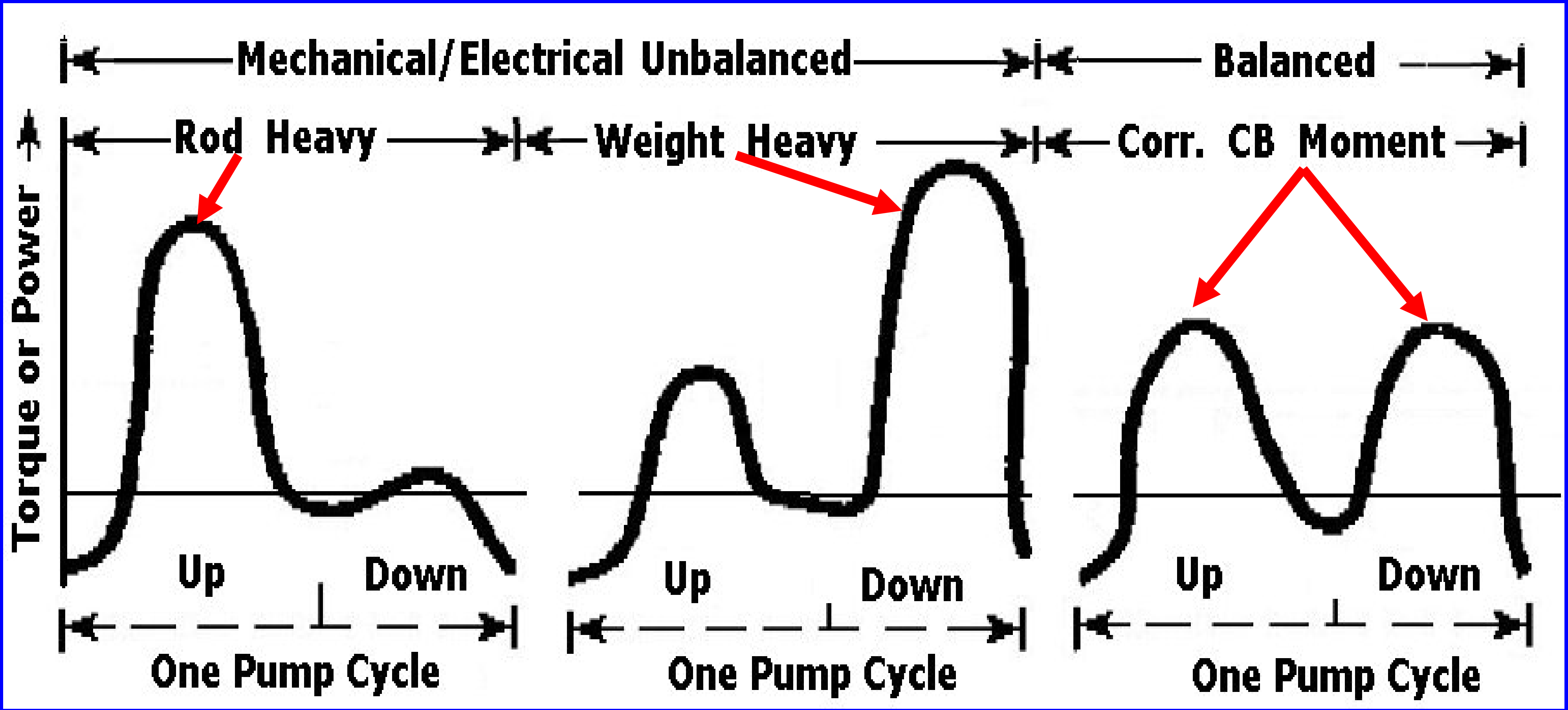
Both show unit weight heavy (overbalanced)

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

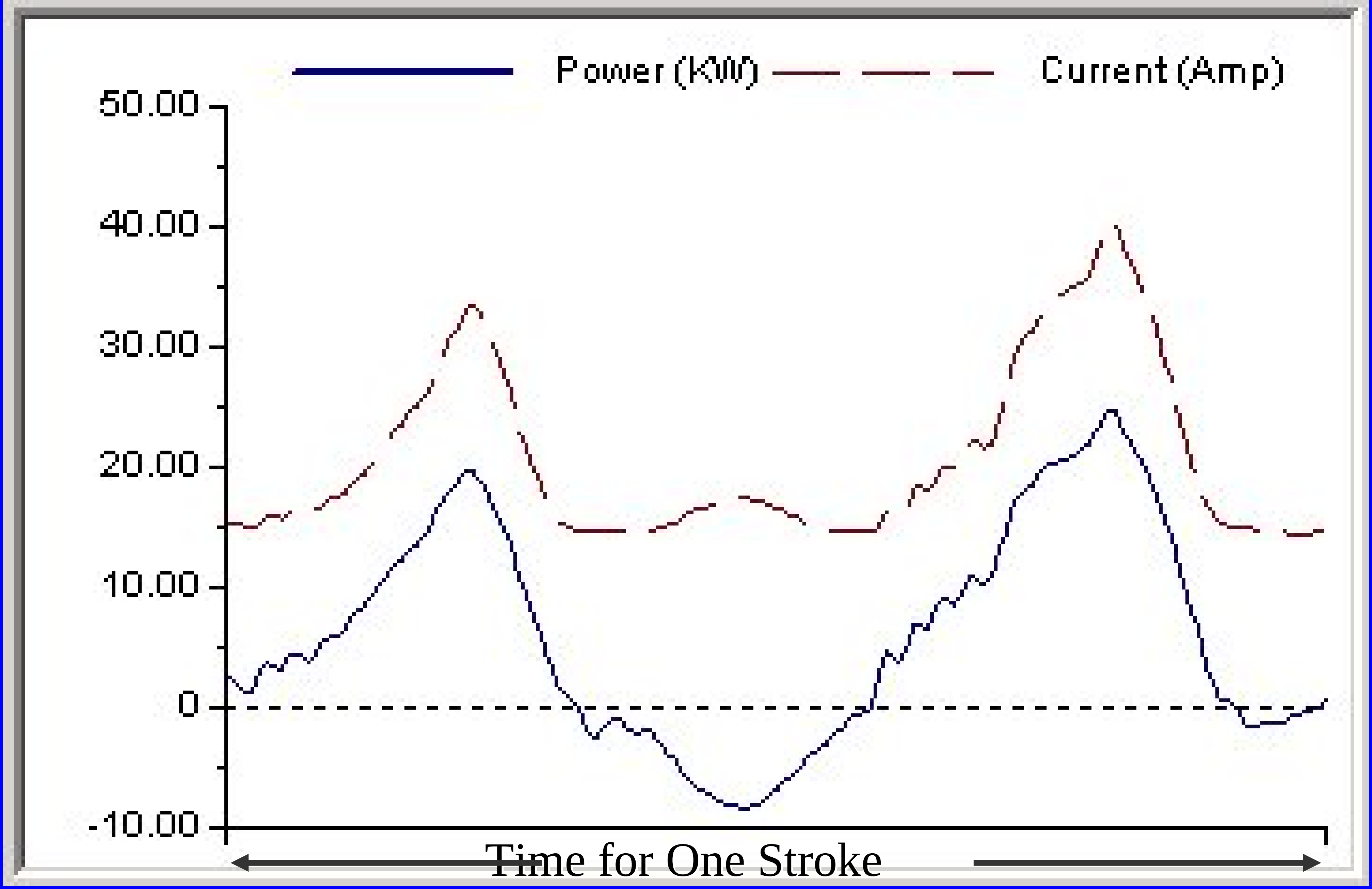


More Uniform Torque Loading Throughout Stroke

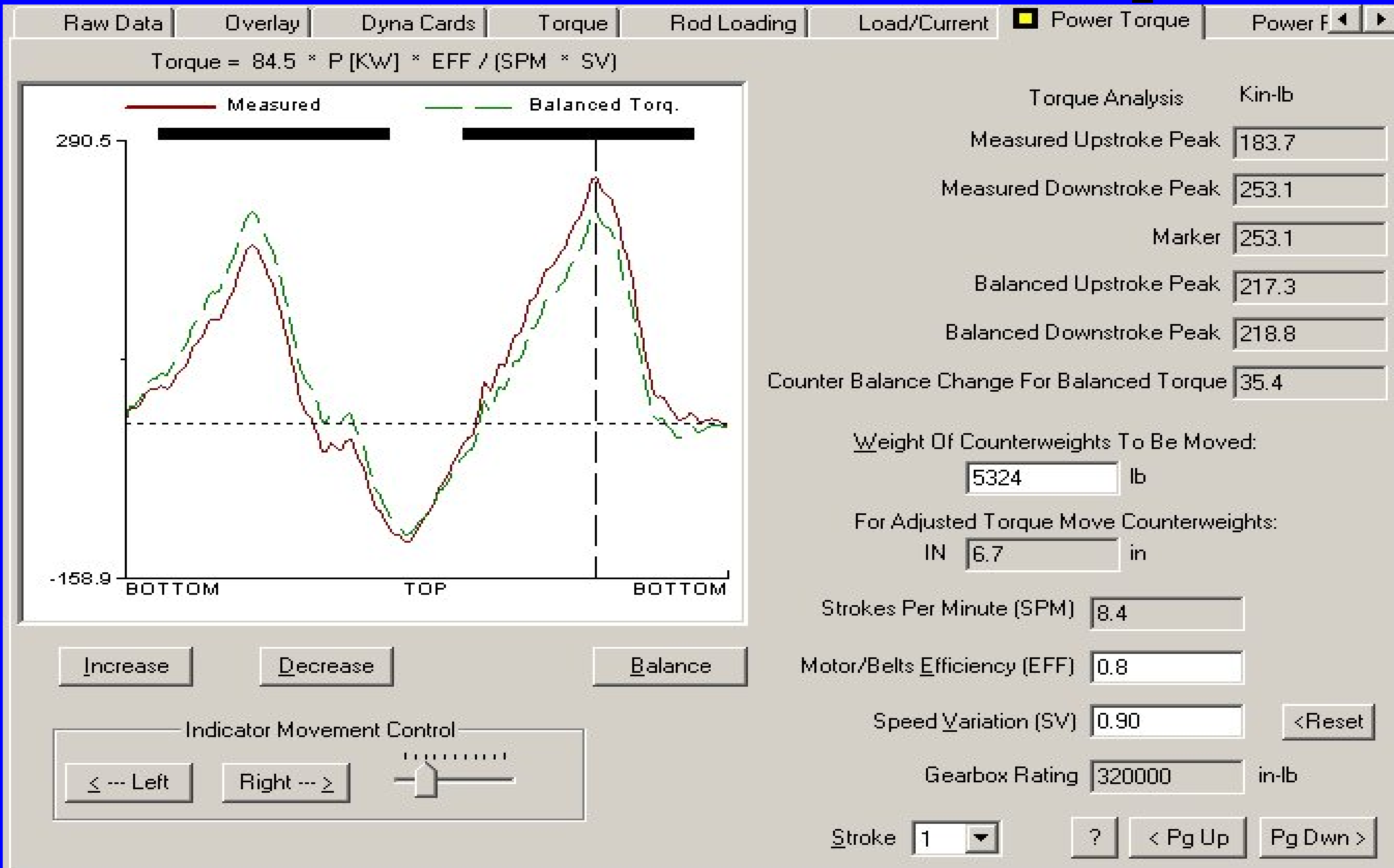
Mechanical/Torque (in-lbs) or Electrical/Power (kW) Signatures for a Unbalanced or Balanced Pumping Unit:



Acquire Electric Power (kW) and Current (Amps) Input to the Motor over the time of a Pump Stroke



Use T_N = 84.5 x kW x Eff / (SPM x 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

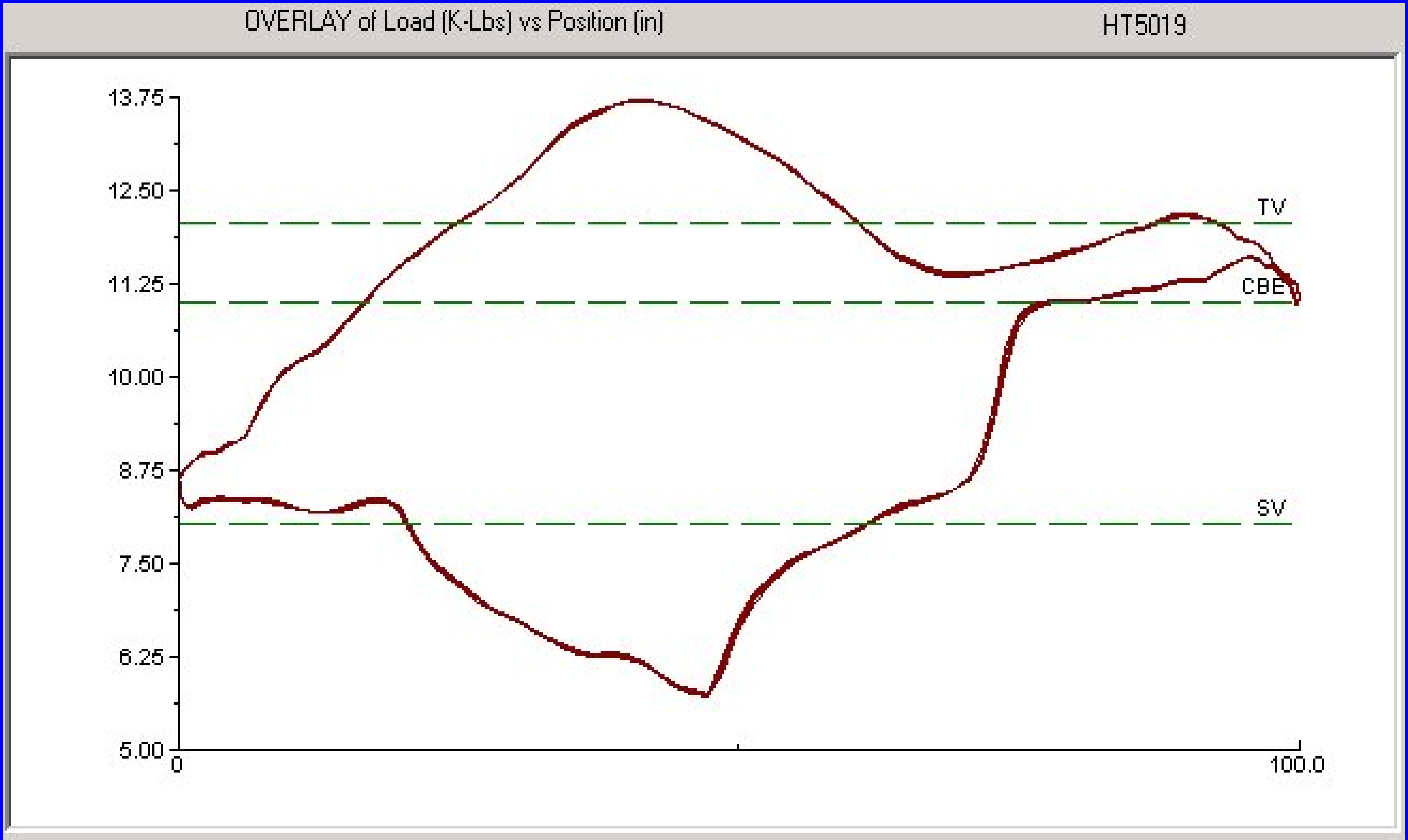
Determine Mechanical Net Gearbox Torque Defined by API Standard 11-E

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



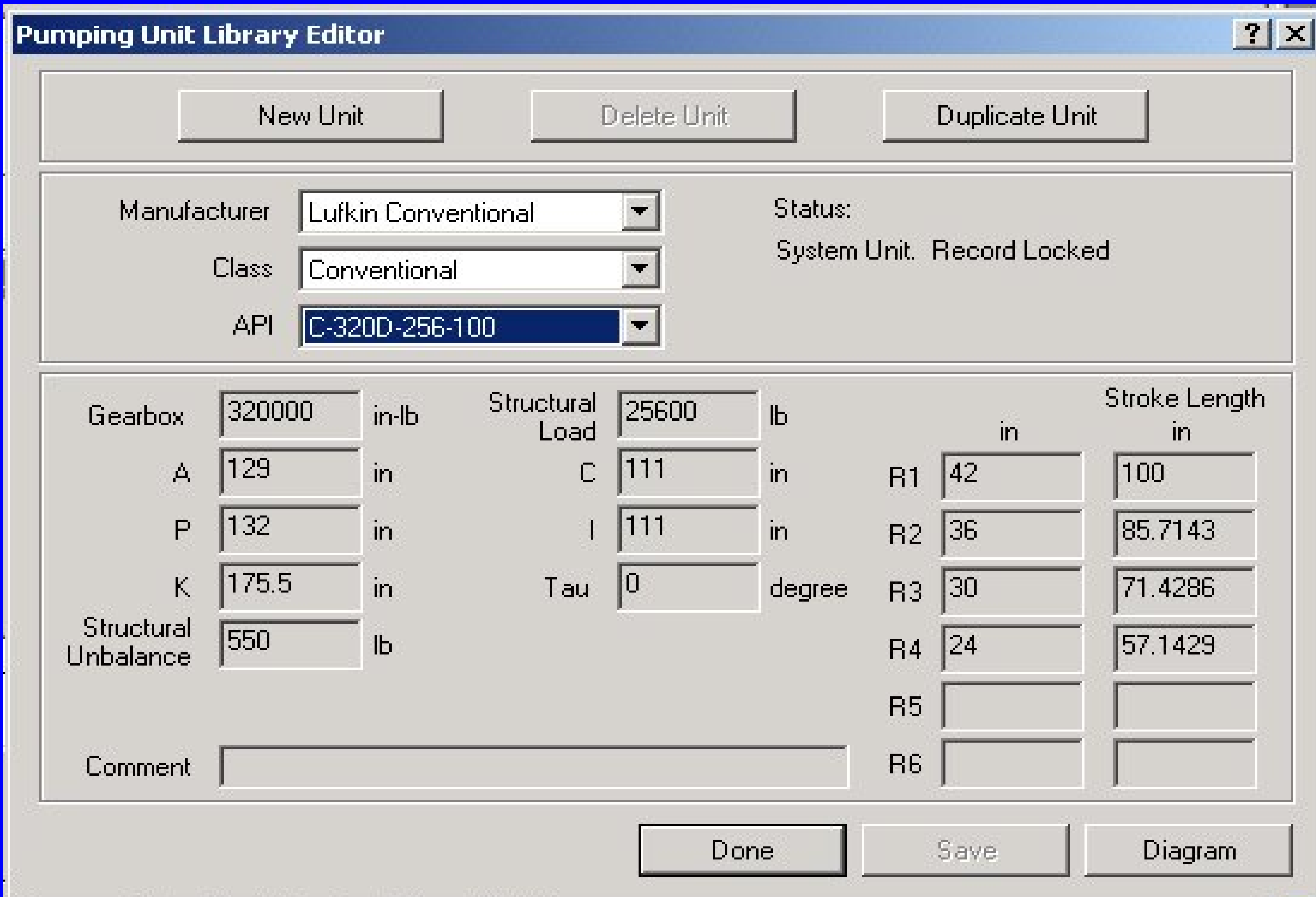
Torque Factors

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

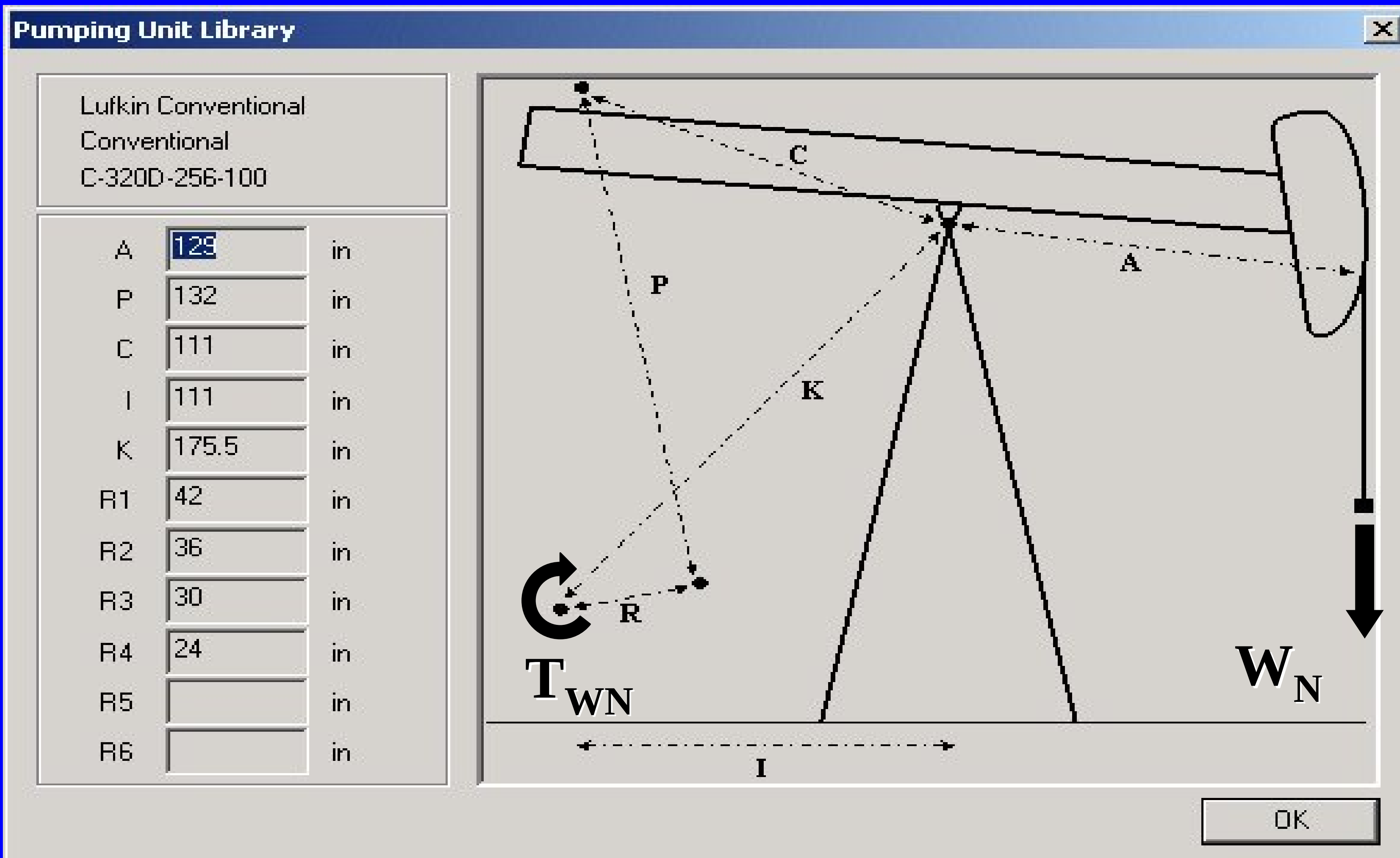
2. Torque factors (TF) are derived from the geometry of the particular pumping unit

3. Used to determine the instantaneous torque due to polished rod load at a given crank position.

Select API Dimensions From Data Base



Torque Factors Derived from Geometry of Selected Pumping Unit



Torque due to Polished Rod Load

Net well load is:

W_N = 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, 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

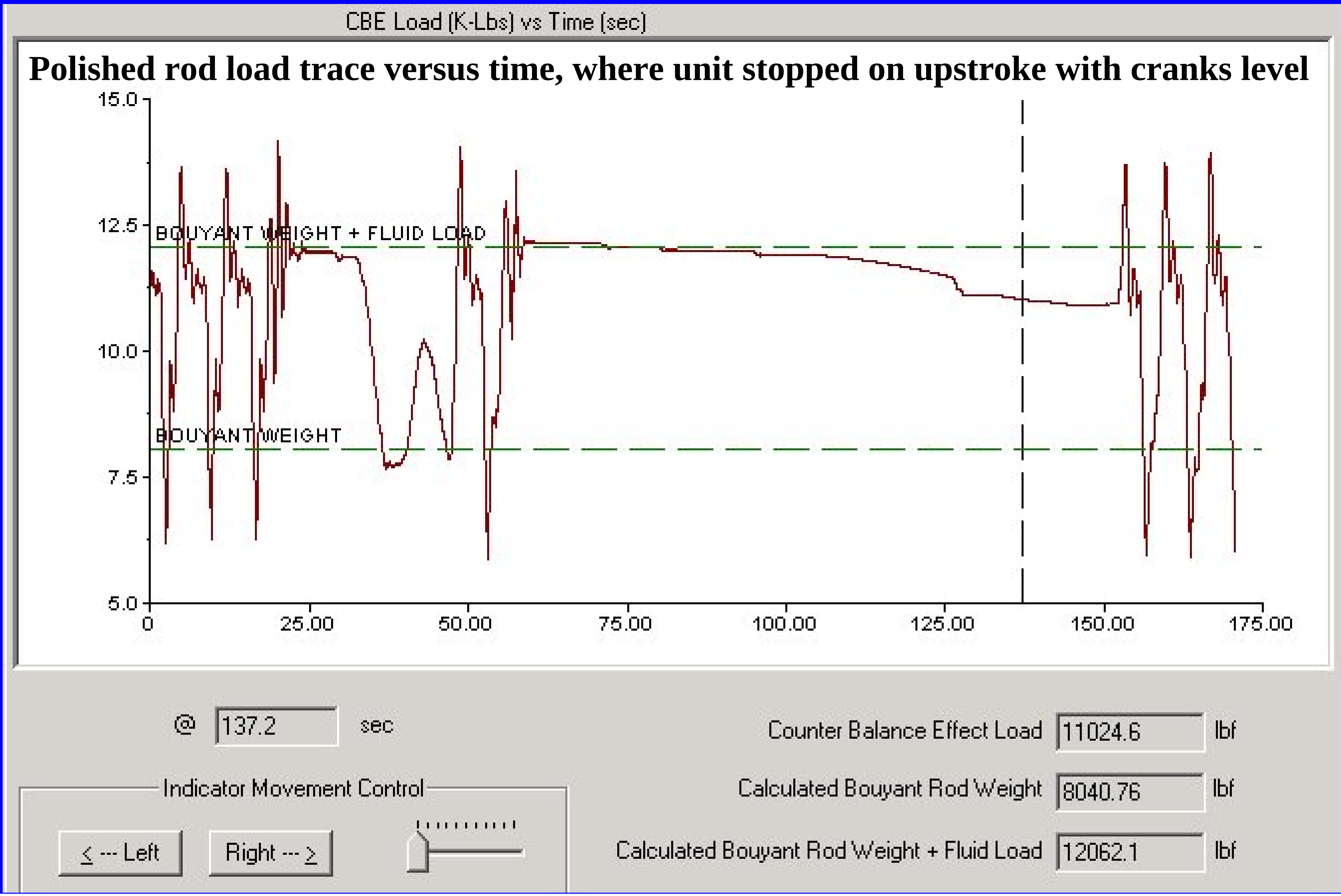
SU = structural unbalance of the pumping unit (either plus or minus value)

TF_{90} = torque factor at 90 Deg crank angle

θ = the crank angle (90)

τ = the crank phase angle

Field Measured CBE with Crank Level Example Well #1



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

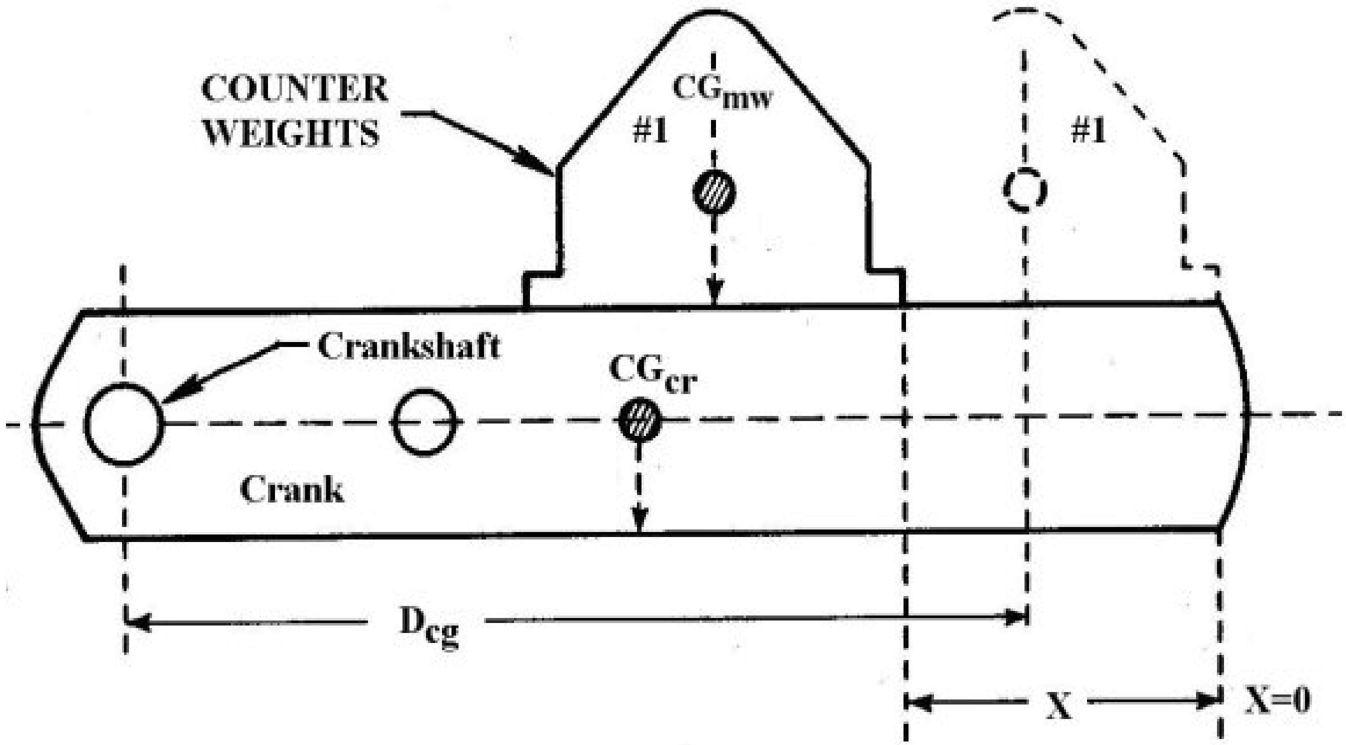
Torque Factor Method is the Standard Method to Determine the Instantaneous Torque Throughout the Pumping Cycle

Use:

- **Polished Rod Load and Position Data**
- **Torque Factors**
- **<u>Together with Counterbalance Moments</u>**

Calculate Counterbalance Moment for Conventional Pumping Units with Crank Mounted Counterweights

$$Me = Mcr + \sum_{i=1}^{Nm} Wm_i \times (Dcg - X_i) + \sum_{i=1}^{Na} Wa_i \times (Dcg - X_i)$$



Where:

- Me = Existing counterbalance moment of the crank and counter weights (in-lbs)
- Mcr = Crank counterbalance moment (in-lbs)
- Wm_i = Weight of the master counterweight (lbs)
- Wa_i = Weight of the auxiliary counterweight (lbs)
- Dcg_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
- Xmax = Maximum distance along crank that counterweight can be moved
- Nm = Number of master counterweights
- Na = Number of auxilary counterweights

Note:

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

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 x 162,338 + 4 x 44,056 = 500,900 in-lbs**

Select Cranks and Counter Weights

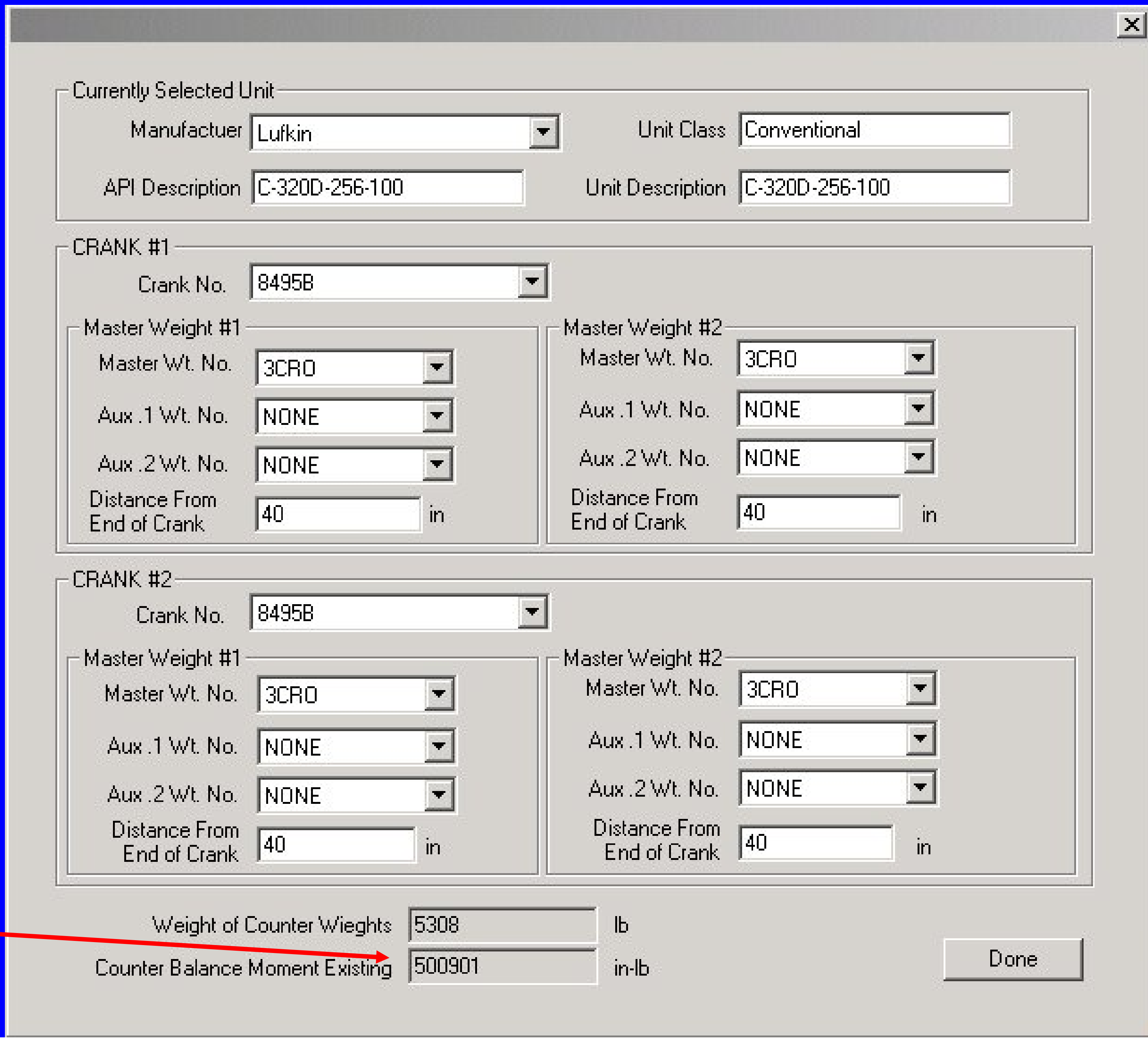
Calculate:

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



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**
- **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:

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

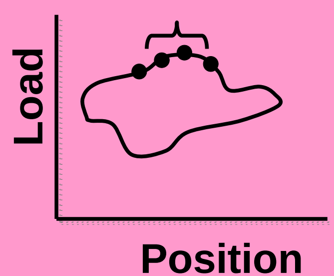
Net Gearbox Torque, T_N

$$T_N = TF(W - SU) - M\,\mathrm{Sin}(\theta + \tau)$$

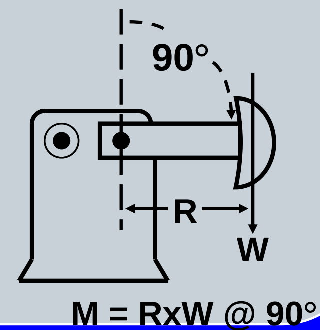
- T_N = net gearbox toque (inch-lbs)
- TF = torque factor at crank angle θ, (in-lbs)/lbs = inch
- W = polished rod load at θ, (lbs)
- SU = structural unbalance of unit (if negative, head falls, lbs)
- M = maximum counter weight moment (in-lbs)
- θ = crank angle (degrees)
- τ = crank offset angle (degrees)

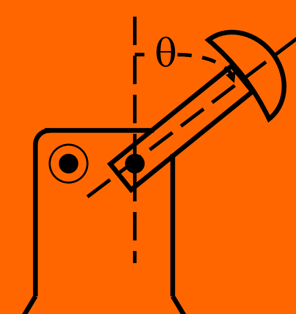
$$T_N = TF(W - SU) - M\,\mathrm{Sin}(\theta + \tau)$$

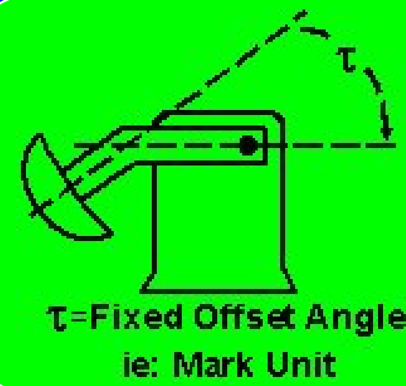
Torque Factor: From tables or calculated, (in-lbf)/lbf, each load & position



Structural unbalance, Lbf, if negative, head falls



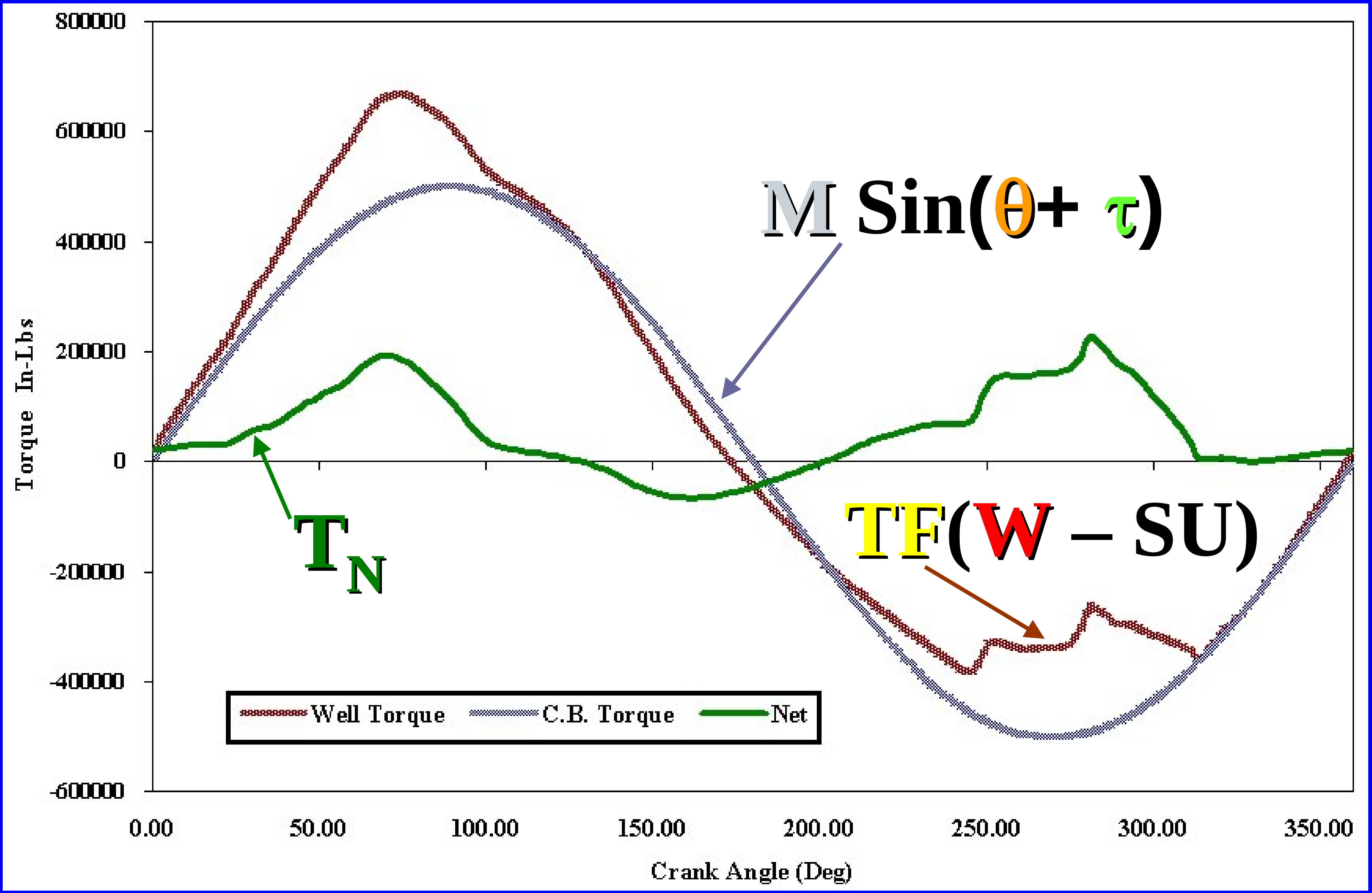




Example of API Standard 11-E Calculations

(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

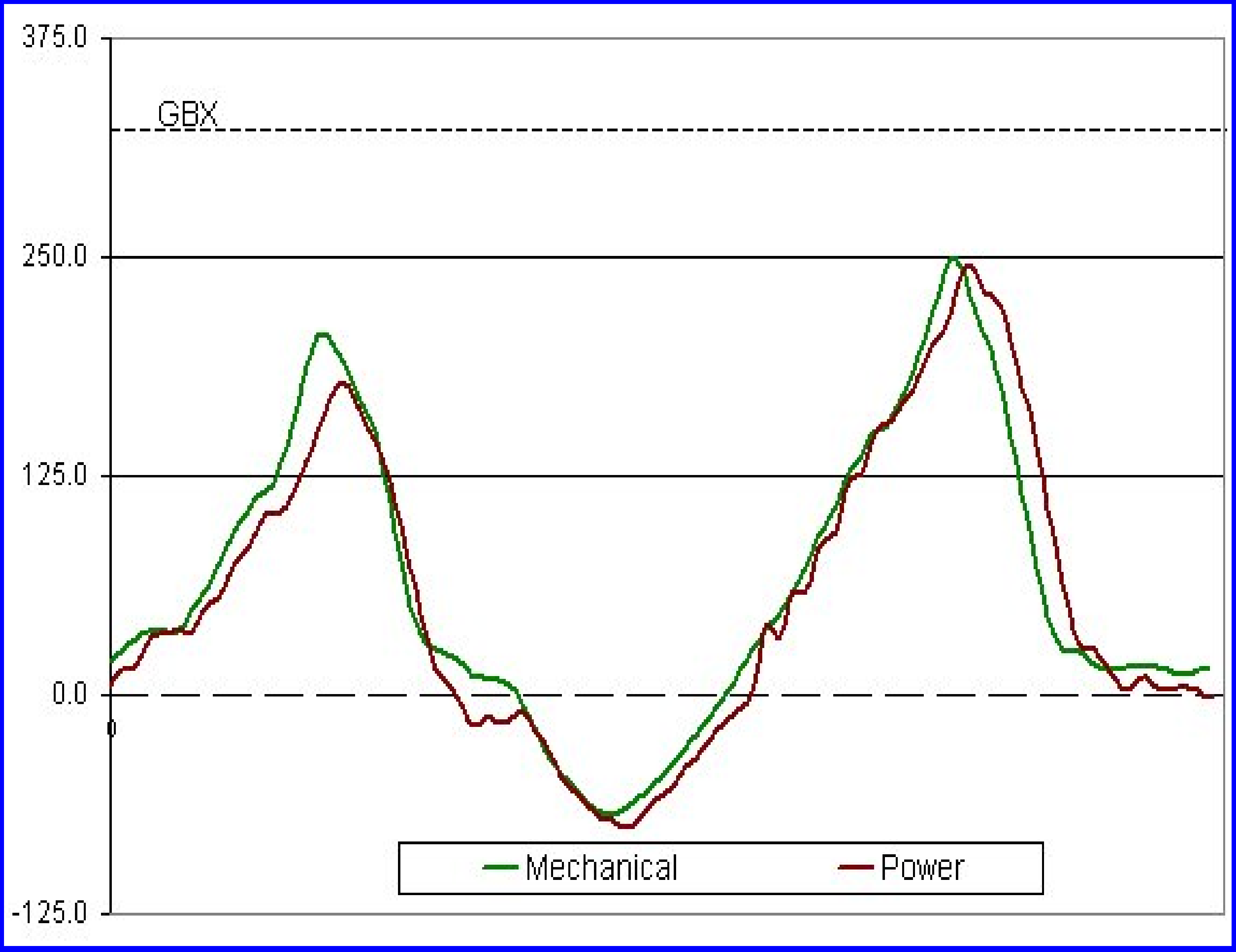
Plot of API Standard 11-E Calculations



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



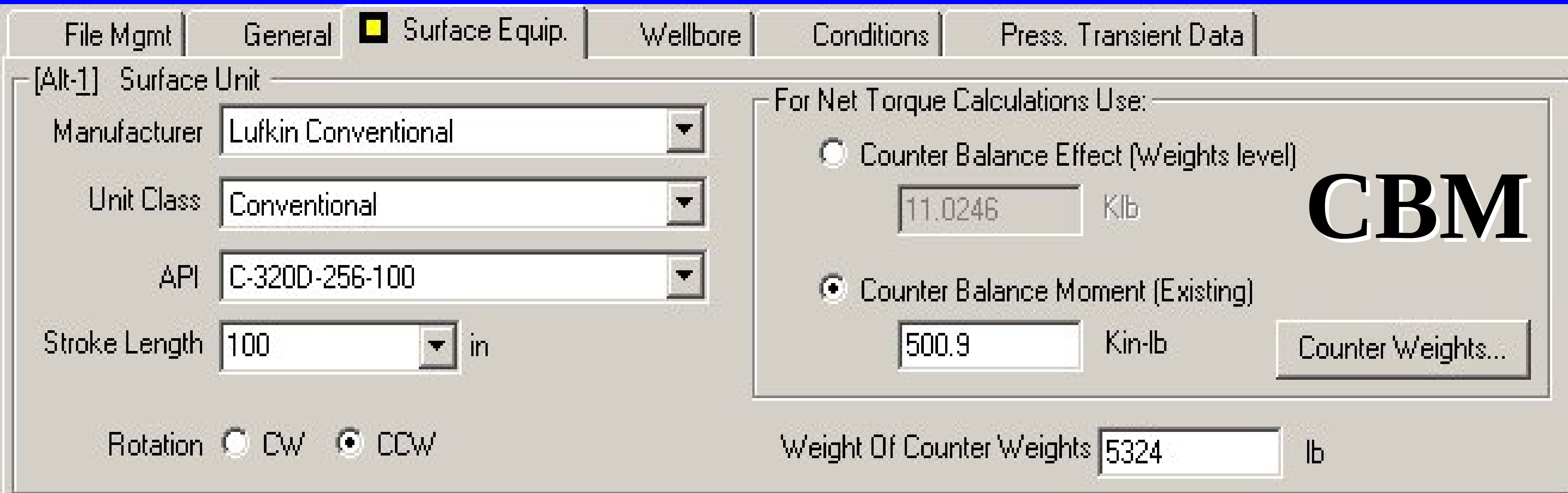
Determine Counterbalance Moment, M, to Balance Peak Torques Between Upstroke and Downstroke

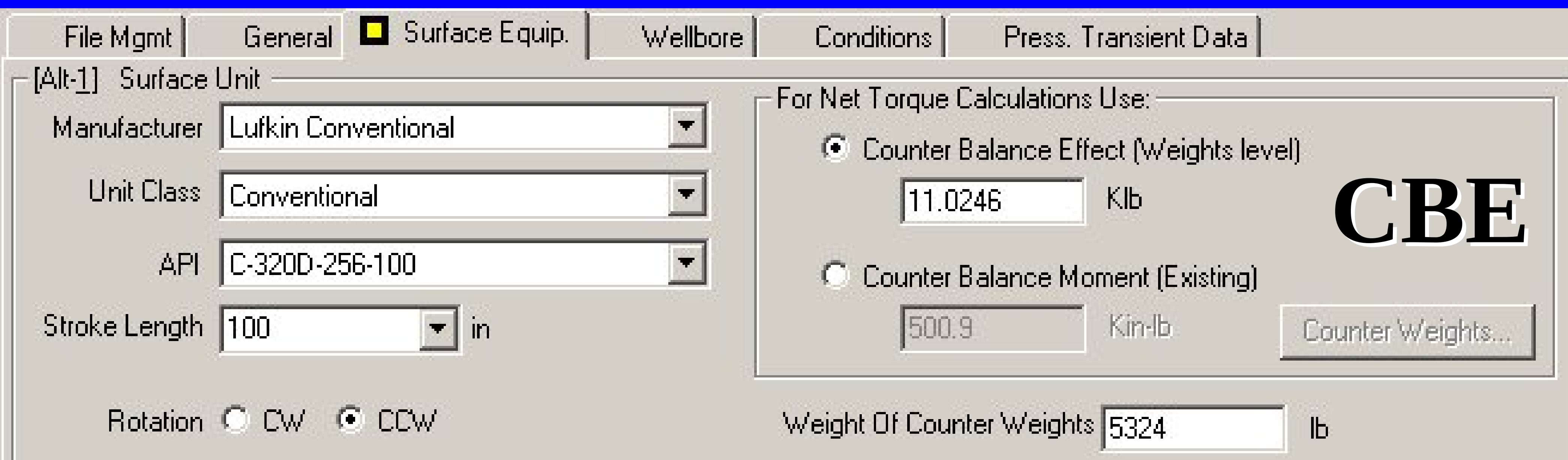
Balancing the peak torques done by equating the upstroke peak, T_{Nu}, to the downstroke peak, T_{Nd}.

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

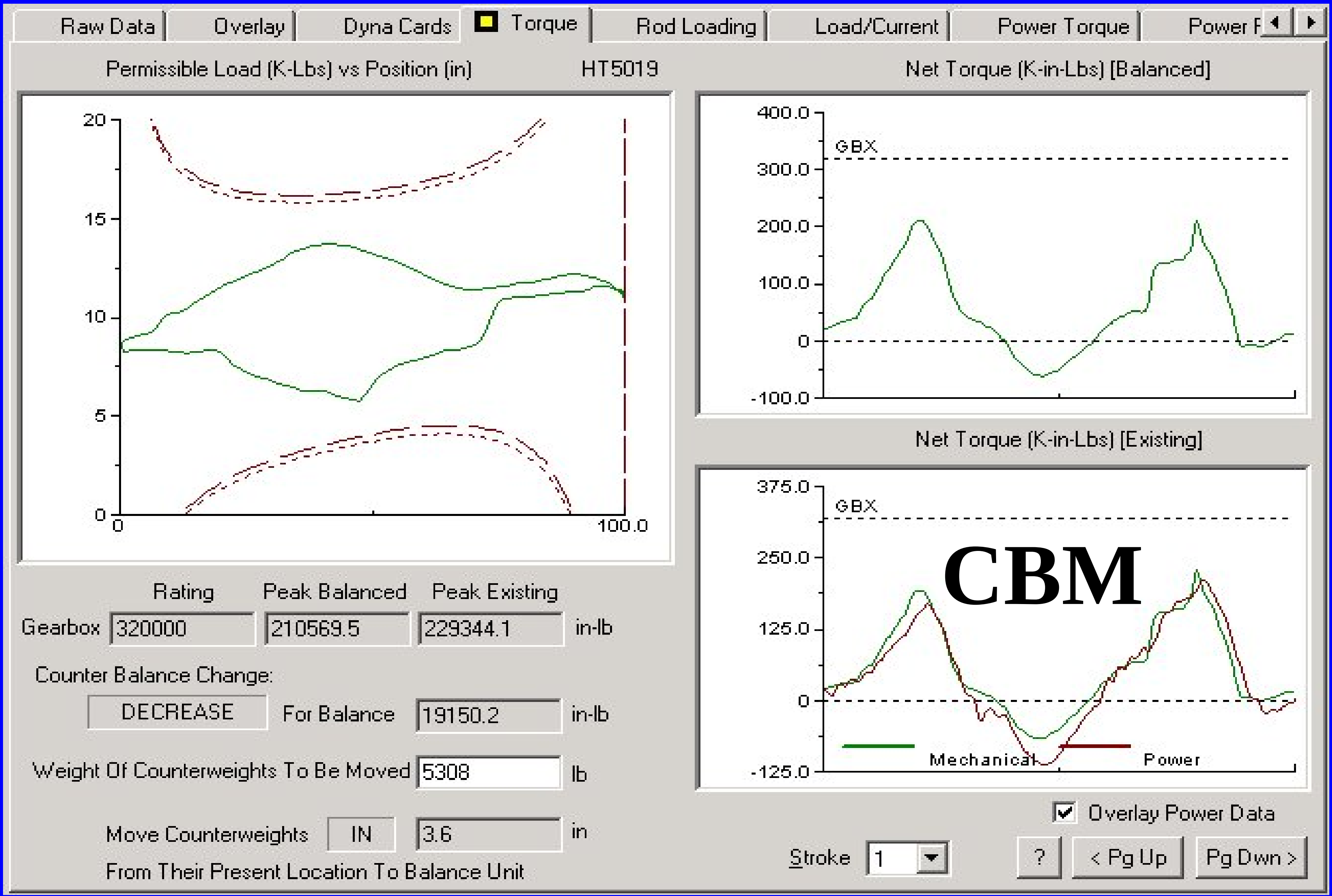
$$M = [TF_d \times (W_d - SU) - TF_u \times (W_u - SU)] / [\sin(\theta_d + \tau) - \sin(\theta_u + \tau)]$$

Select Mechanical Torque Method

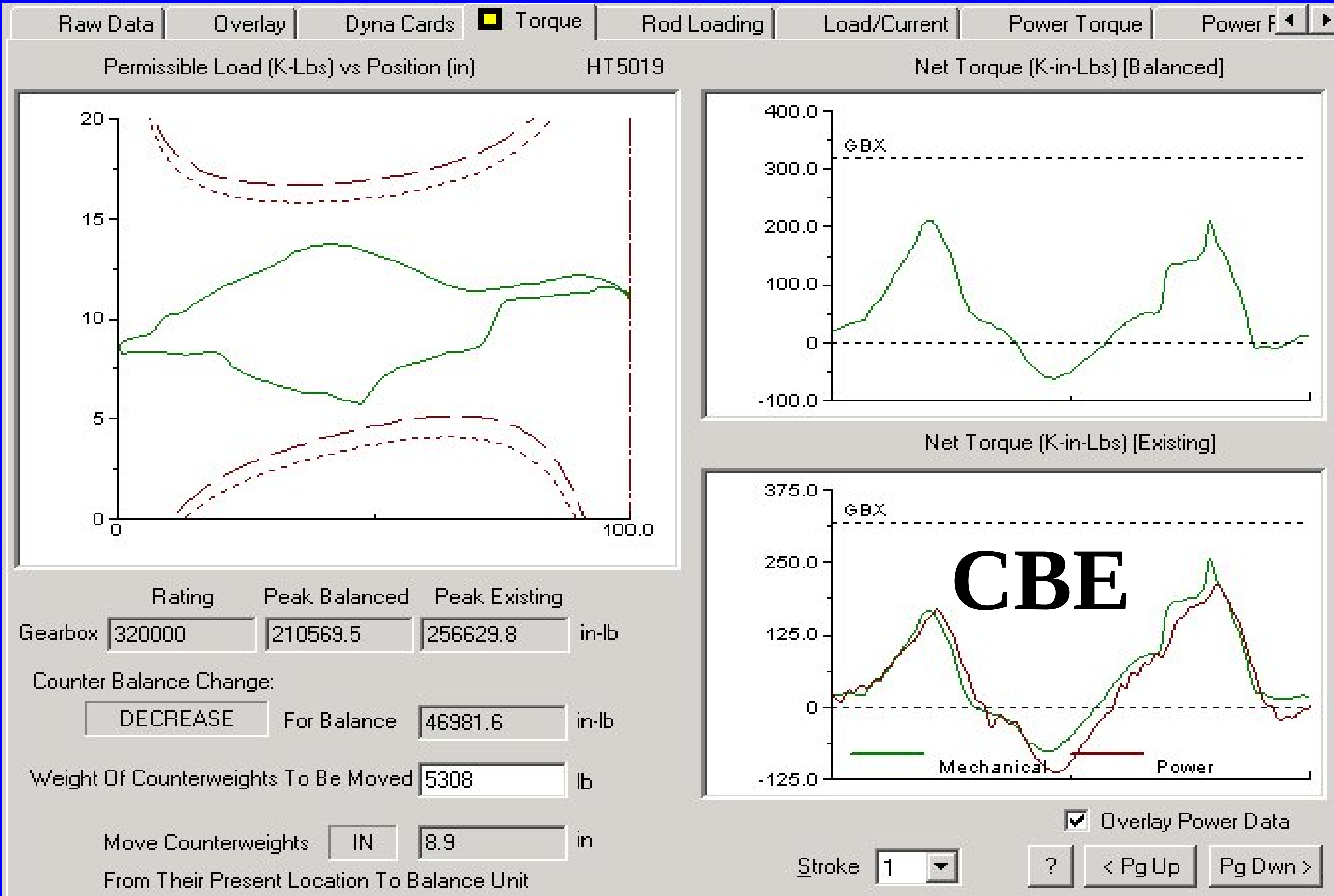




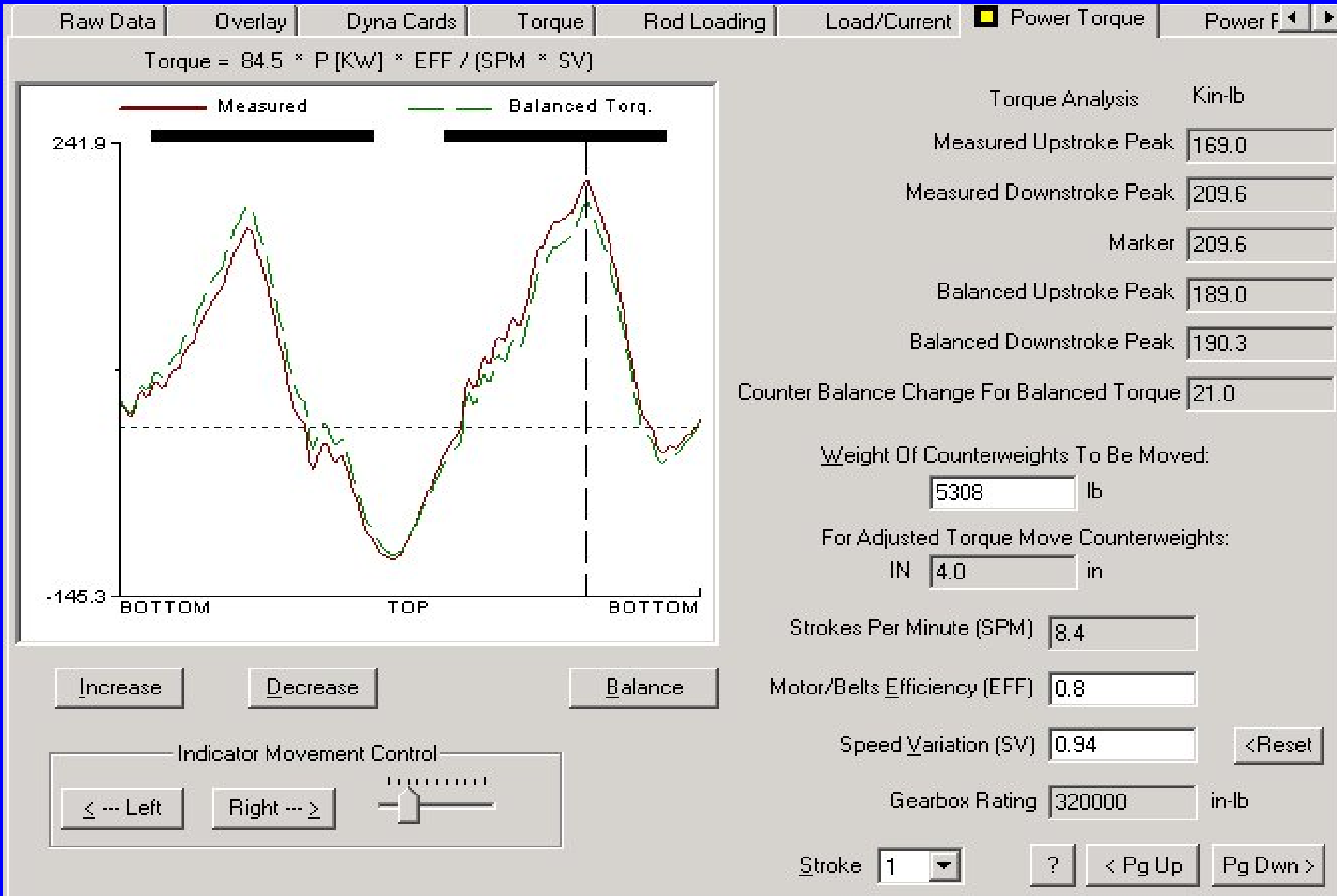
Net Gearbox Torque - Mechanical



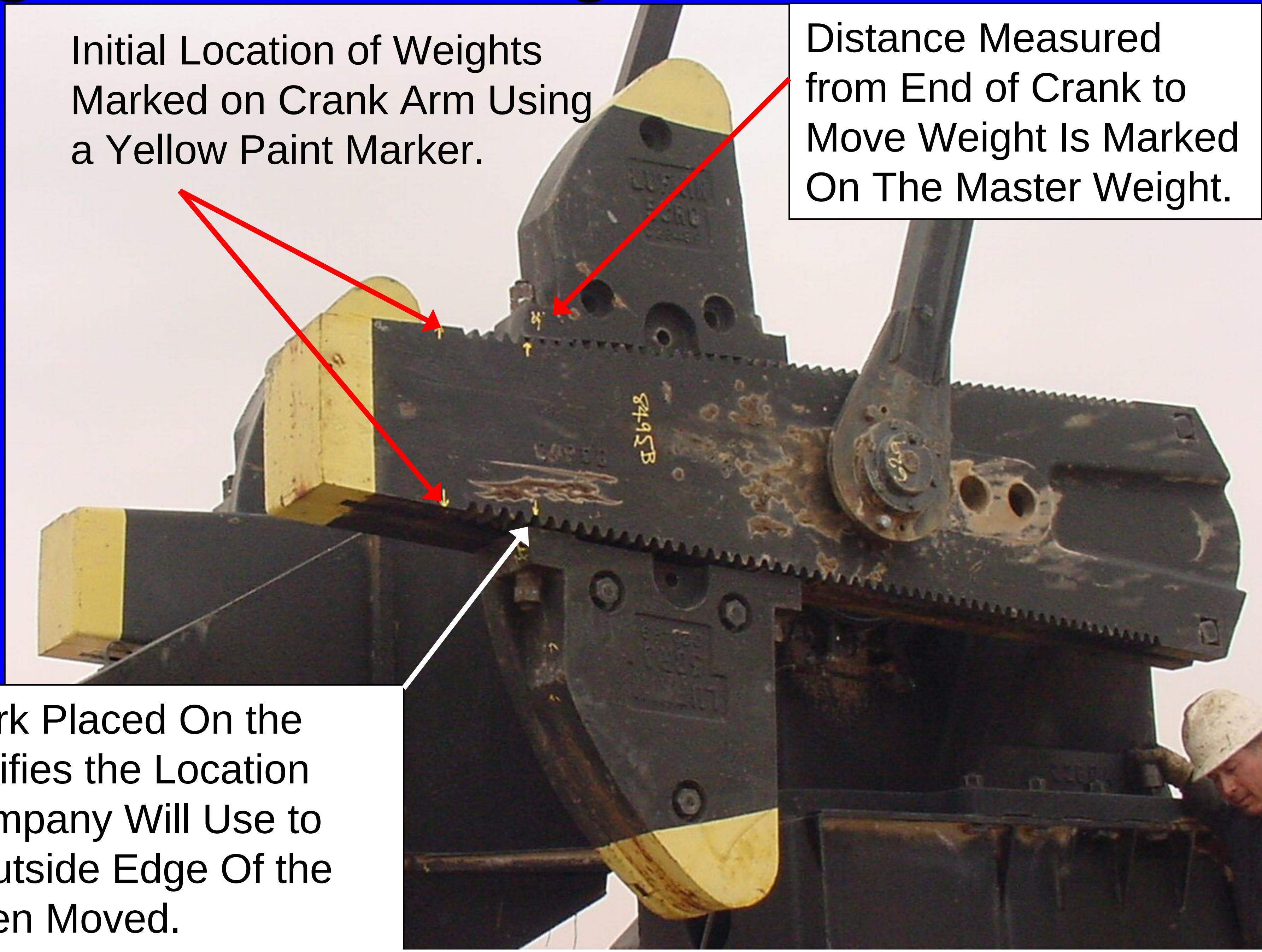
Net Gearbox Torque - Mechanical



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 ?