Evaluation Of Pumping Unit Capacity

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For many years among operating personnel it has been common knowledge that beam type pumping units would operate more satisfactorily if rotated in their preferred direction of rotation. With the widespread advent of electrical powered units, this pronounced difference in operating characteristics became a matter of concern to many operators. Since the direction of rotation could be easily changed and observations made of this variation in performance, they were able to select the optimum direction of rotation and operate the unit in the direction which gave the best performance.

Strangely, though this behavior characteristic was common knowledge, many years passed before any effort was made to predict or explain why this was true. Additional years passed before any attempt was made to utilize this knowledge by designing a pumping unit with a special direction of rotation which would have greatly improved operating characteristics.

The purpose of this paper is to:

1. Present why conventional units have a preferred direction of rotation.
2. Give a method for selecting this preferred direction of rotation.
3. Give a method for determining the true load capacity of a pumping unit for either direction of rotation.
4. Present the improved operating characteristics of units having special directions of rotation.

It is very easy to understand why conventional units have a preferred direction of rotation. It is evident that if the tailbearing could be moved in a straight line (Figure 1), extended vertically up from the slow speed shaft, equal crank angles either toward, or away from, the well would result in identical crank moment arms but the beam moment arm would be much shorter with the cranks toward the well. A load lifted with the cranks in this forward position would require a much larger pitman stress, and, since crank moment arms are identical, a much larger torque would be required.

In the actual unit, however, the tailbearing moves in an arc, having as its center the saddle bearing (Figure 2). Constrained to this arc the tailbearing center is displaced horizontally toward the saddle bearing as it moves above and below the horizontal. This horizontal movement changes the pitman angle with respect to the wrist pin circle and identical crank angles necessarily must have different moment arms and pitman forces. (Figures 1 & 2). Factually, then, it is impossible to have a pumping unit with identical load lifting, and torque characteristics in both directions of rotation. Units, which have their slow speed shaft located directly under the tailbearing and at right angles to a line through tailbearing and saddle bearing centers when beam and cranks are horizontal, are the most nearly bi-directional in all respects. The greater the deviation from this location and linkage arrangement, the more pronounced are the differences in operating characteristics.

Noting that all units have pronounced differences in load and torque capacities which are related to their direction of rotation, we need a method to evaluate which direction of rotation offers the greatest advantages for our application. Permissible load calculations and permissible load diagrams offer a simple and correct solution to this problem. Since this method evaluates gear reducer capacity directly in terms of polished rod load capacity, it is possible to evaluate direction of rotation on a quantitative basis. In addition, the permissible load diagram enables us to visualize this true load capacity. A visual comparison of the unit capacity and the well load record from the dynamometer dictates immediately the proper direction of rotation.

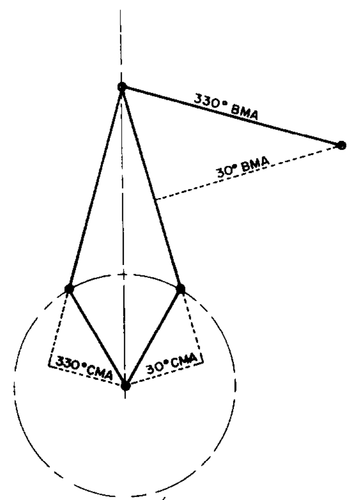


FIGURE 1
VERTICAL TAILBEARING MOVEMENT

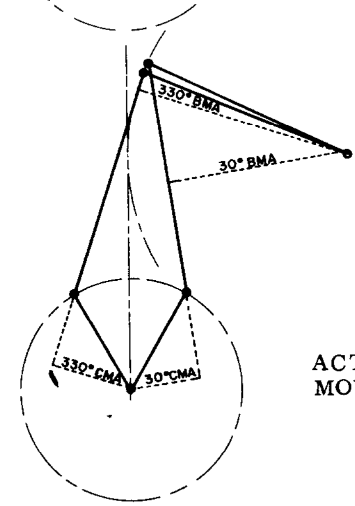


FIGURE 2
ACTUAL TAILBEARING MOVEMENT

The calculation of permissible loads and the construction of a permissible load diagram requires the use of API Pumping Unit stroke and Torque Factors furnished for the particular unit under consideration by the manufacturer. "Torque Factors are conversion factors which convert load at the polished rod to torque at the gear reducer. The torque factor at a given crank position multiplied by net well load at that position gives the instantaneous torque due to the net well load." (D. O. Johnson, Torque Factors for Pumping Units, 1959 WTOLSC, Lubbock, Texas). They are functions of the unit geometry and consequently apply only to the particular unit for which they are calculated.

Torque factors ($\overline{TF}$ Tables 1 & 2) are commonly used in determining actual gear reducer torque requirements from dynamometer card records of well loads. The formula for their use is:

Net Reducer Torque = $\overline{TF}$ (W-B)-MSin0.

Where: W = Measured Polished Rod Load (Lbs.) at position of rods corresponding to 0.
M = Maximum moment of counterbalance (90° or 270°)
O = Position of crank, Degrees (0° at top vertical position of crank, rotation clockwise)
B = Structural unbalance of the unit

The procedure for their use is as follows:

1. Measure card length.
2. Multiply this length by rod position factor for each of the positions. This locates the position of the polished rod for each 15° crank position.
3. Transfer these stroke positions by measurement to the dynamometer card.
4. Measure recorded load at this polished rod position and calculate load in pounds.
5. Subtract from this measured load unit unbalance to determine net load at this position.
6. Multiply this net load times the torque factor for this position to find net torque from well load.
7. Find maximum counterbalance moment from tables or if counterbalance was weighed, find maximum counterbalance moment by the following equation:
   M = (Measured C.B. Effect - Unit Unbalance) $\overline{TF}$
   (Be sure that $\overline{TF}$ for 90° is used if counterbalance was weighed at 90° or TF for 270° if weighed at 270°. Counterbalance effect as recorded in Manufacturers Tables are for 90° crank angle).
8. Multiply maximum counterbalance torque by the sine of the crank angle being used to determine actual torque developed by the counterbalance at this position. (Counterbalance torque is assigned a negative value on the upstroke 0 to 180° and a positive value on the downstroke 180° to 360°).
9. Add algebraically net torque from well load and net torque from counterbalance to determine actual net torque on the gear reducer.

In the calculation of permissible loads and the construction of permissible load diagrams, the above procedure is reversed. Our aim is to determine what load can be carried at the well end by a fully loaded gear reducer. The procedure for doing this is as follows: (Table 1 and 2)

1. Determine the maximum counterbalance moment (torque) of the effective counterbalance available (or to be purchased).
2. Find actual counterbalance torque for each corresponding crank angle by multiplying maximum counterbalance torque by the sine of that crank angle. Since we are reversing the procedure, we assign positive values to counterbalance values from 0 to 180° upstroke, and negative values from 180° to 360° downstroke.
3. Add algebraically to these counterbalance torque values the maximum reducer torque rating of the gear reducer to find total torque available for lifting load on the upstroke, or the remaining counterbalance torque which must be lifted with well load on the downstroke.
4. Divide these torques by the torque factor for the corresponding crank angle to find load capacity from counterbalance and gear reducer.
5. Add to these loads the unit unbalance. This value is the maximum load which can be lifted at this crank position by a fully loaded gear reducer.
6. Assume card length; or, if diagram is to be plotted to scale of dynamometer card, use length of usual dynamometer card.
7. Multiply this length by rod position factors to find location on card.
8. Plot permissible load to scale at this position.
9. Plot true counterbalance effect line by the same method after finding true counterbalance effect for each crank position by the following formula:

$$CBE = \frac{M \sin 0 - B}{TF}$$

The permissible load diagrams (Figures 3 and 4) just constructed define pictorially the unit load capacity in terms of macimum gear reducer capacity. Any upstroke loads greater than this load limit line would overload the reducer on the upstroke. Any downstroke loads less than the downstroke load limit line would also overload the reducer. Any upstroke load line which crosses the true upstroke counterbalance effect line would show negative torque as would any downstroke load which crossed the true downstroke counterbalance effect line. If this diagram is constructed to the same scale and length as a dynamometer card taken with the unit, comparison can be made on a direct basis. With counterbalance lines matched, any load line on the dynamometer card which crosses the permissible load lines shows reducer overload and any line which crosses the true counterbalance line will cause negative torque. Note particularly the difference in counterbalance effect which is required for the same approximate load capacity. With this parameter, direct comparisons can be made of a unit in both directions of rotation after permissible loads are calculated for each direction of rotation. The differences in load capacity are plainly apparent and best direction of rotation can be chosen (Figure 5).

This method of comparison is also very useful in making comparisons between units of different make or geometry. The additional capacity available with some unit configurations is immediately evident and the large additional capacity available with a unit having special geometry and designed to rotate in a specified direc

Bethlehem PUMPING UNITS

ENGINEERING DATA

320-256-120

320-213-120

API PUMPING UNIT STROKE AND TORQUE FACTORS

1	2	3	4	5	6	7	8	9
POSITION OF CRANK DEGREES (1)	POSITION OF RODS (2) LENGTH OF STROKE - INCHES				TORQUE FACTOR (3) (4) LENGTH OF STROKE - INCHES			
	120	102	85	67	120	102	85	67
0	0.000	0.000	0.000	0.000	- 2.96	- 1.74	- 0.93	- 0.42
15	0.017	0.018	0.018	0.019	18.53	15.68	12.83	10.03
30	0.080	0.079	0.078	0.077	38.68	31.83	25.48	19.60
45	0.181	0.177	0.172	0.168	53.66	44.07	35.28	27.16
60	0.306	0.299	0.291	0.283	61.15	50.81	41.12	31.97
75	0.440	0.431	0.421	0.412	61.51	52.10	42.88	33.88
90	0.569	0.561	0.552	0.542	56.99	49.24	41.29	33.17
105	0.685	0.680	0.673	0.666	49.96	43.84	37.32	30.44
120	0.784	0.783	0.780	0.776	41.99	37.12	31.85	26.23
135	0.866	0.868	0.868	0.867	33.73	29.68	25.44	20.96
150	0.930	0.934	0.936	0.937	25.15	21.68	18.29	14.90
165	0.974	0.978	0.980	0.982	15.86	12.94	10.43	8.19
180	0.997	0.999	0.999	1.000	5.25	3.21	1.84	0.96
195	0.996	0.993	0.991	0.989	- 7.15	- 7.65	- 7.40	- 6.62
210	0.965	0.959	0.954	0.949	-21.14	-19.27	-16.93	-14.20
225	0.904	0.895	0.887	0.880	-35.34	-30.71	-26.05	-21.29
240	0.814	0.804	0.794	0.785	-47.69	-40.61	-33.88	-27.29
255	0.700	0.691	0.681	0.670	-56.50	-47.82	-39.62	-31.64
270	0.573	0.563	0.553	0.543	-61.09	-51.70	-42.69	-33.93
285	0.439	0.430	0.421	0.411	-61.48	-52.04	-42.86	-33.91
300	0.310	0.301	0.292	0.284	-57.87	-48.82	-40.01	-31.46
315	0.192	0.185	0.177	0.170	-50.22	-42.04	-34.16	-26.61
330	0.095	0.090	0.085	0.080	-38.46	-31.72	-25.41	-19.54
345	0.029	0.026	0.024	0.022	-22.53	-18.06	-14.09	-10.60
		MAXIMUM TORQUE FACTORS						
65.3	0.380				62.11			
276.1	0.492				-61.82			

(1) Position of crank is the angular displacement measured clockwise from the 12 o'clock position, viewed with the well head to the right.

(2) Position is expressed as a fraction (percentage) of stroke above lowermost position.

(3) Torque factor = $\frac{T}{W}$ where T = torque on pumping-unit reducer due to polished rod load W.

(4) Negative signs on torque factor indicate a clockwise torque on crankshaft.

NET REDUCER TORQUE = $\overline{TF}$ (W-B) $-$M SIN θ

Where θ = Position of Crank Degrees (See Col. 1 above)

M = Maximum Moment of Counterbalance (See Page 4)

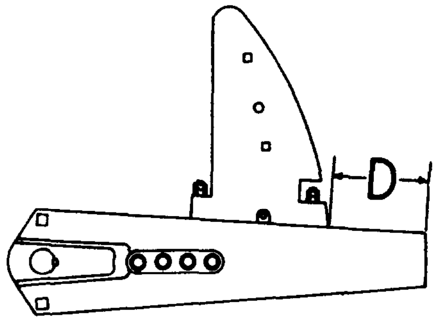
W = Measured Polish Rod Load (Lbs.) At Position Of Rods Corresponding to θ.

B = Structural Unbalance = 200#

$\overline{TF}$ = Torque Factor Corresponding to θ.

$\overline{TF}$ TABLE 1. 9-25-62

320-256-120
320-213-120



**API RATING FORM
FOR
CRANK COUNTERBALANCE**

TWO #8495-B CRANKS - TOTAL WEIGHT - 7020# MOMENT - 324,675"#

ABOVE TOTAL WEIGHT AND MOMENT OF TWO #8495-B CRANKS
IS INCLUDED IN FIGURES SHOWN BELOW

Distance "D" Counterweights From End Of Crank	4 Main Weights #95		One Filler Weight #95		4 Main Weights and 12 Filler Weights #95	
	Total Weight	Total Moment	Total Weight	Total Moment	Total Weight	Total Moment
0"	11,700	687,843	7,515	362,641	17,640	1,143,443
6"	"	659,763	"	359,671	"	1,079,721
12"	"	631,683	"	356,701	"	1,016,001
18"	"	603,603	"	353,731	"	952,281
24"	"	575,523	"	350,761	"	888,561
30"	"	547,443	"	347,791	"	824,841
36"	"	519,363	"	344,821	"	761,121
42"	"	491,283	"	341,851	"	697,401
48"	"	463,203	"	338,881	"	633,681
54"	"	435,123	"	335,911	"	569,961
60" (Max.)	"	407,043	"	332,941	"	506,241

Distance "D" Counterweights From End Of Crank	4 Main Weights #78		One Filler Weight #78		4 Main Weights and 12 Filler Weights #78	
	Total Weight	Total Moment	Total Weight	Total Moment	Total Weight	Total Moment
1-1/4"	10,200	571,443	7,425	355,860	15,060	945,663
6"	"	556,338	"	353,936	"	907,473
12"	"	537,258	"	351,506	"	859,233
18"	"	518,178	"	349,076	"	810,993
24"	"	499,098	"	346,646	"	762,753
30"	"	480,018	"	344,216	"	714,513
36"	"	460,938	"	341,786	"	666,273
42"	"	441,858	"	339,356	"	618,033
48"	"	422,778	"	336,926	"	569,793
54"	"	403,698	"	334,496	"	521,553
60"	"	384,618	"	332,066	"	473,313
62" (Max.)	"	374,283	"	330,750	"	447,183

NOTE: To obtain moment of one filler weight deduct moment of cranks (324,675"#) from total moment of one filler weight.

9-25-62

TF TABLE 2

TABLE 1.

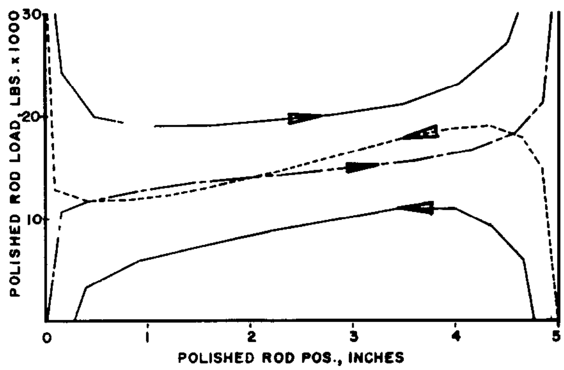
Permissible Load Calculations
320-256-120 Counterclockwise Rotation (Figure 3)
Counterbalance Effect 14,900# (1) C.B. Moment = (14,900 - 200) (61.09) = 900,000"#
(7) Card Length = 5"
Unit Unbalance = + 200#

	(2)		(3)		(4)	(5)	(6)	(7)		(9)
Deg.	C.B Torque x 1000"#	Unit Torque x 1000"#	Torque Available x 1000"#	Torque Factor	Permis. Load x 1000#	Per Load Unit UB (200#) x 1000#	P.R. Pos %	P.R. Pos Inches	Act. CB Effect x1000#	CBE + UB x 1000#
0	0	320	320	2.96	108.1	107.9	.000	0	0	.2
15	233.1	320	553.1	22.53	24.54	24.52	.029	.15	10.3	10.5
30	450.0	320	770.1	38.46	20.02	20.04	.095	.47	11.7	11.9
45	636.3	320	956.3	50.22	19.04	19.06	.192	.96	12.7	12.9
60	779.4	320	1099.4	57.87	18.99	19.1	.310	1.55	13.5	13.7
75	869.4	320	1189.4	61.48	19.34	19.5	.439	2.19	14.2	14.4
90 (1)	900	320	1220	61.09	19.97	20.2	.573	2.86	14.7	14.9
105	869.4	320	1189.4	56.50	21.05	21.2	.700	3.50	15.4	15.6
120	779.4	320	1099.4	47.69	23.05	23.2	.814	4.07	16.3	16.5
135	636.3	320	956.3	35.34	27.06	27.2	.904	4.52	18.0	18.2
150	450.3	320	770.1	21.14	36.42	36.6	.965	4.83	21.3	21.5
165	233.1	320	553.1	7.15	77.35	77.5	.996	4.98	32.6	32.8
180	0	320	320	- 5.25	- 60.95	- 60.7	.997	4.99	0	.2
195	- 233.1	320	86.9	- 15.86	- 5.47	- 5.6	.974	4.87	14.7	14.9
210	- 450.0	320	- 130	- 25.15	5.17	5.4	.930	4.65	17.9	18.1
225	- 636.3	320	- 316.3	- 33.73	9.37	9.5	.866	4.33	18.9	19.1
240	- 779.4	320	- 459.4	- 41.99	10.94	11.1	.784	3.92	18.6	18.8
255	- 869.4	320	- 549.4	- 49.96	10.99	11.1	.685	3.42	17.4	17.6
270	- 900	320	- 580	- 56.99	10.17	10.3	.569	2.85	15.8	16.0
285	- 869.4	320	- 549.4	- 61.51	8.93	9.1	.440	2.20	14.1	14.3
300	- 779.4	320	- 459.4	- 61.15	7.51	7.7	.306	1.53	12.7	12.9
315	- 636.3	320	- 316.3	- 53.66	5.89	6.0	.181	.90	11.9	12.1
330	- 450.0	320	- 130	- 38.68	3.36	3.5	.080	.40	11.6	11.8
345	- 233.1	320	86.9	- 18.53	- 4.68	- 4.8	.017	.085	12.6	12.8

TABLE 2

Permissible Load Calculations
320-256-120 Clockwise Rotation (Figure 4)
Counterbalance Effect 16,000# (1) C.B. Moment = (16,000-200) (56.99) = 900,000"#
(7) Card Length 5"
Unit Unbalance = + 200#

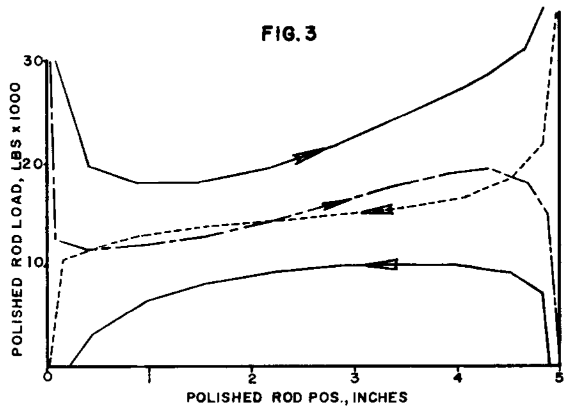
	(2)		(3)		(4)	(5)	(6)	(7)		(9)
Deg.	C.B. Torque x 1000"#	Unit Torque x 1000"#	Torque Available x 1000"#	Torque Factor	Permis. Load # x 1000#	Per Load Unit UB (200#)	P.R. Pos %	P.R. Pos. Inches	Act. CB Effect x 1000#	Act.CBE + UB x 1000#
0	0	320	320	- 2.96	- 108.1	- 107.9	.000	0	0	.2
15	233.1	320	553.1	18.53	29.9	30.1	.017	.09	12.6	12.8
30	450.0	320	770.0	38.68	19.9	20.1	.080	.40	11.6	11.8
45	636.3	320	956.3	53.66	17.8	18.0	.181	.91	11.9	12.1
60	779.4	320	1099.4	61.15	17.9	18.1	.306	1.53	12.7	12.9
75	869.4	320	1189.4	61.51	19.3	19.5	.440	2.20	14.1	14.3
90	(1) 900	320	1220	56.99	21.4	21.6	.569	2.84	15.8	16.0
105	869.4	320	1189.4	49.96	23.8	24.0	.685	3.42	17.4	17.6
120	779.4	320	1099.4	41.99	26.2	26.4	.784	3.92	18.5	18.7
135	636.3	320	956.3	33.73	28.4	28.6	.866	4.33	18.9	19.1
150	450.0	320	770.1	25.15	30.6	30.8	.930	4.65	17.9	18.1
165	233.1	320	553.1	15.86	34.9	35.1	.974	4.87	14.7	14.9
180	0	320	320	5.25	60.9	61.1	.997	4.98	0	.2
195	- 233.1	320	86.9	- 7.15	- 12.1	- 11.9	.996	4.98	32.6	32.8
210	- 450.0	320	- 150	- 21.14	7.1	7.3	.965	4.82	21.3	21.5
225	- 636.3	320	- 316.3	- 35.34	8.9	9.1	.904	4.52	18.0	18.2
240	- 779.4	320	- 459.4	- 47.69	9.6	9.8	.814	4.07	16.3	16.5
255	- 869.4	320	- 549.4	- 56.50	9.7	9.9	.700	3.50	15.4	15.6
270	- 900	320	- 580	- 61.09	9.5	9.7	.573	2.86	14.7	14.9
285	- 869.4	320	- 549.4	- 61.48	8.9	9.1	.439	2.19	14.1	14.3
300	- 779.4	320	- 459.4	- 57.87	7.9	8.1	.310	1.55	13.5	13 7
315	- 636.3	320	- 316.3	- 50.22	6.3	6.5	.192	.96	12.7	12.9
330	- 450.0	320	- 130	- 38.46	3.3	3.5	.095	.47	11.7	11.9
345	- 233.1	320	86.9	- 22.53	- 3.8	- 3.6	.029	.14	10.3	10.5



320-256-120 CCW ROTATION

14,900 LBS. C.B.E.

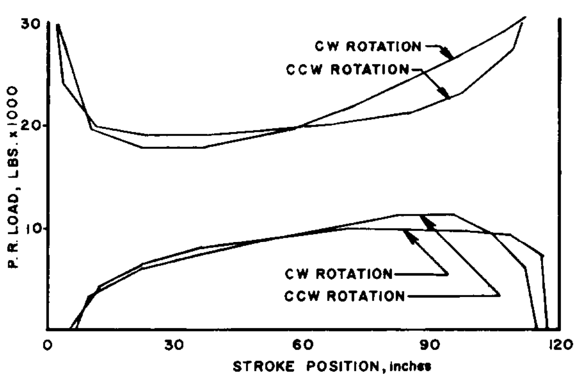
FIG. 3



320-256-120 CW ROTATION

16,000 LBS. C.B.E.

FIG. 4



320-256-120 CW vs CCW ROTATION

16,000 & 14,900 LBS CBE

FIG. 5

tion can be readily evaluated.

In the past torque factors have been used rather widely as a comparative measure of this unit efficiency and capacity. Commonly used for this comparison are the maximum upstroke torque factor and the torque factor at 90°. An examination of the unit load capacity diagrams, above, will show that torque factors alone are of little value as a comparative measure. Since both the counterbalance and the gear reducer must work together to lift the well end load, true unit capacity evaluation must include this counterbalance effect. Note that the least upstroke load capacity of the fully loaded gear reducer does not occur at the point of maximum torque factor. Observation of the permissible load calculations shows that the maximum reduction in upstroke load capacity occurs because the torque available from the counterbalance is limited and the torque factor at this position is large with respect to its theoretical value. The theoretical value of a torque factor for a given position is one half the stroke length multiplied by the sine of the crank angle. For a 120 in. stroke unit this would be:

Crank Angle	S/2 (in.)	Sine 0	Theoretical TF
30°	60	.500	30.00
45°	60	.707	42.42
60°	60	.866	51.96
75°	60	.966	57.96
90°	60	1.000	60.00

Comparison of actual torque factors at the same crank positions will show a higher percentage of deviation early in the stroke than at the point of maximum torque factor. The total reduction in capacity is the combined result of low counterbalance torque working with the gear reducer, which has a disproportionately large torque arm, to lift a well load.

In view of the foregoing it is evident that even purportedly bi-directional units show wide disparity in their load capacities when their direction of rotation is changed. Until recently no designer had deliberately set out to design a unit with a specified direction of rotation. In recent years the first uni-directional unit was introduced as a front mounted pumping unit which was designed to operate in the counter clockwise direction. In this design the gear reducer was mounted in front of the samson post and use was made of rotary type counterbalance mounted opposite the wrist pin holes. This counterbalance was offset a fixed angle from line through slow speed shaft and wrist pin in an effort to achieve uniform torque. Its design and operating characteristics were covered rather fully in a paper presented at the 1962 meeting of the WTOLSC.

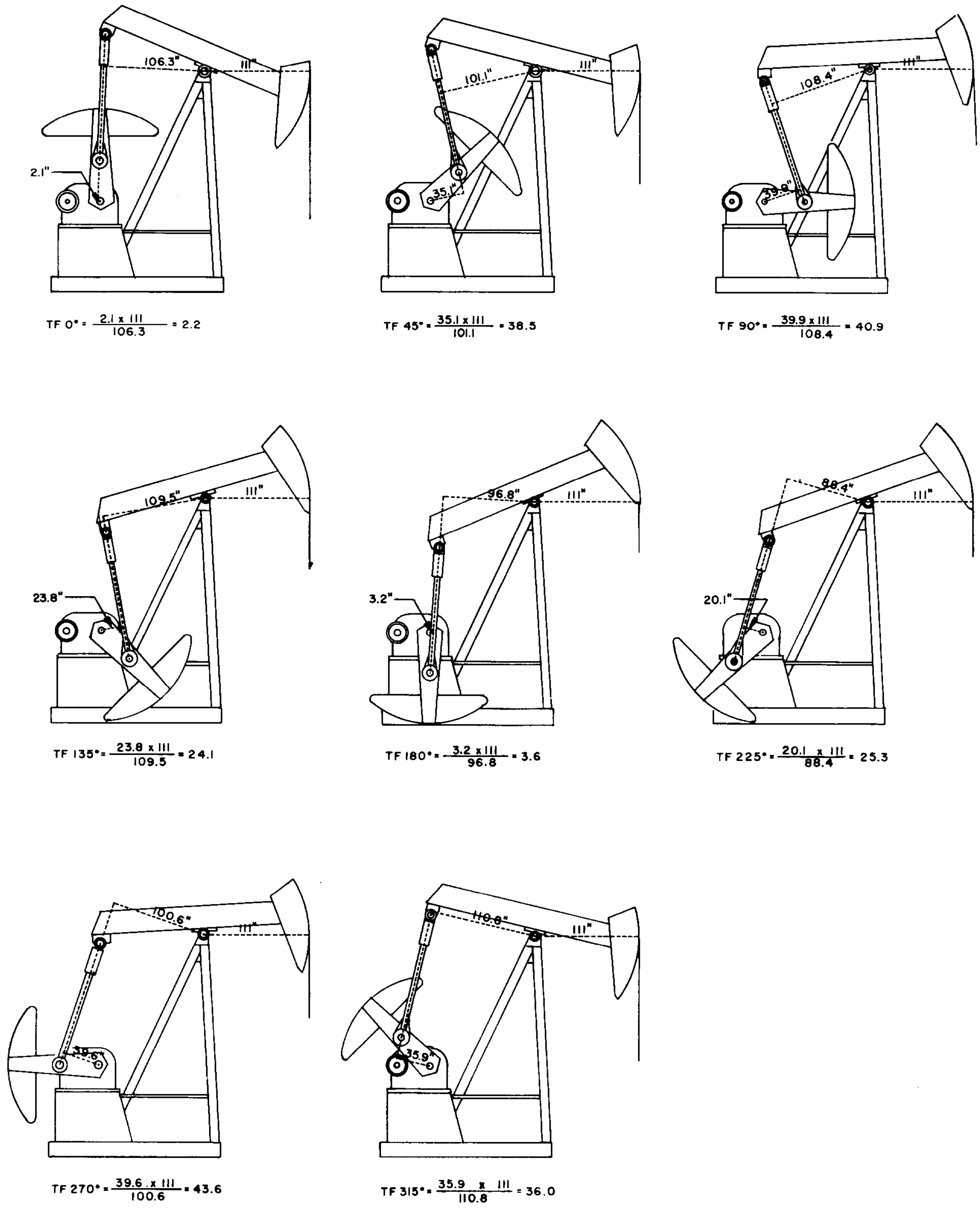
Patent application has been made on another unit with a specified direction of rotation which has been designed and is currently in manufacture. It can be built to operate with either a clockwise or counter clockwise rotation, but is currently being manufactured to rotate in the clockwise direction. It is a conventional unit design with gear reducer mounted behind the samson post in the conventional manner. Counterbalance is of the conventional rotary type and other components are very similar to those found in conventional units. The only change has been in the location of the links in the kinematic chain.

The following are changes made for clockwise rotation:

A. Pitman length is shorter
B. Tailbearing location is lower
C. Rear working center is longer
D. Front working center is shorter

In this design the movement of the tailbearing is predominantly downward. At its uppermost position it is only slightly above a horizontal line passing through the saddle bearing. The slow speed shaft is located directly under the tailbearing when it reaches its uppermost position so that this dead center position occurs at 0° crank angle. Counterbalance torque is also zero at this point.

This design eliminates the enforced negative



$$TF\ 0° = \frac{2.1 \times 111}{106.3} = 2.2$$

$$TF\ 45° = \frac{35.1 \times 111}{101.1} = 38.5$$

$$TF\ 90° = \frac{39.9 \times 111}{108.4} = 40.9$$

$$TF\ 135° = \frac{23.8 \times 111}{109.5} = 24.1$$

$$TF\ 180° = \frac{3.2 \times 111}{96.8} = 3.6$$

$$TF\ 225° = \frac{20.1 \times 111}{88.4} = 25.3$$

$$TF\ 270° = \frac{39.6 \times 111}{100.6} = 43.6$$

$$TF\ 315° = \frac{35.9 \times 111}{110.8} = 36.0$$

FIG. 8

320-246-86

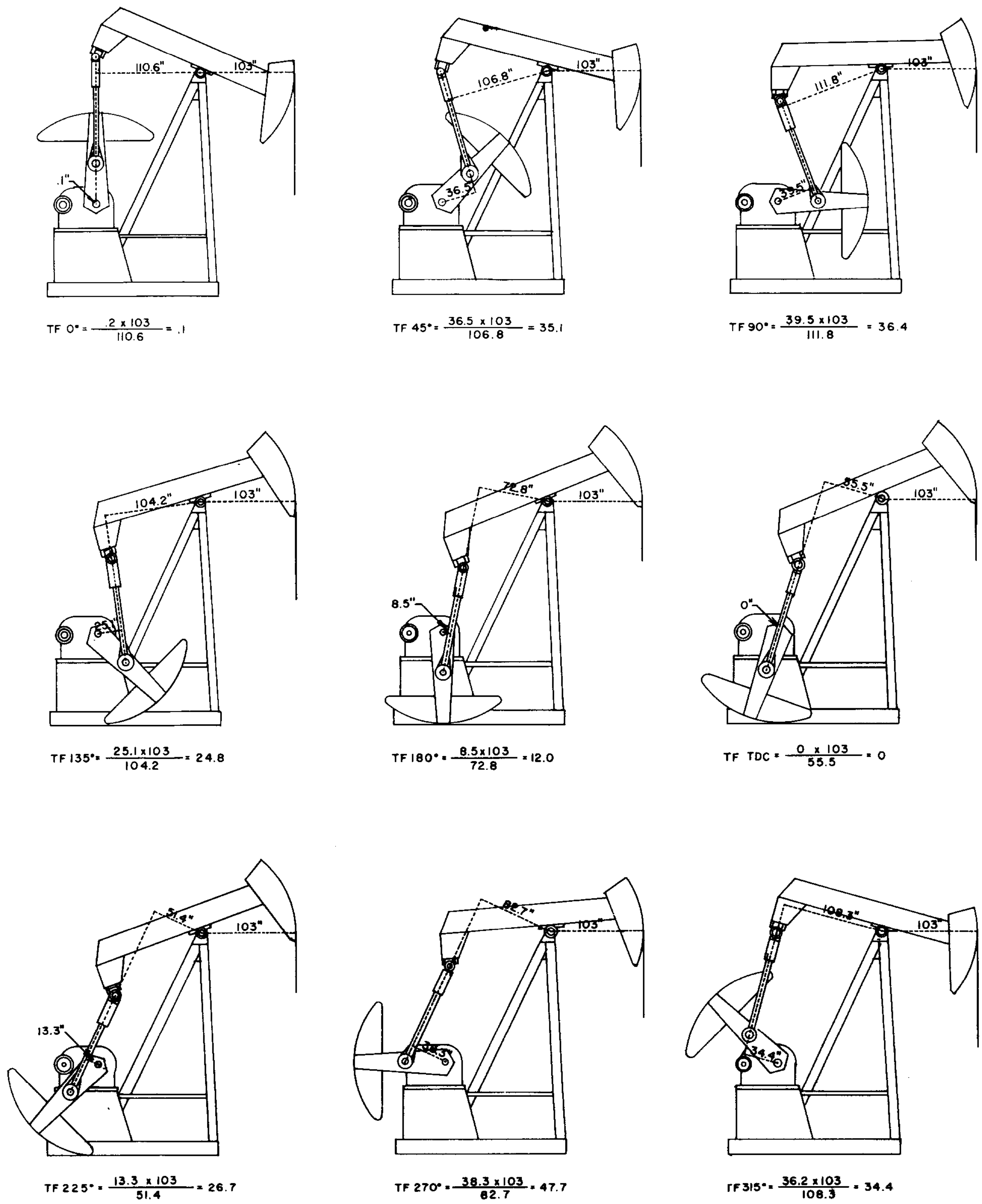


FIG.9 320-246-BG-86

torque found in conventional unit designs in which top vertical (0°) is reached before top dead center (7° to 15°) is reached and a negative torque from well load is induced. Figures 8 and 9 will demonstrate what happens as the unit passes through the various crank positions. Note particularly the relative length of the rear moment arm on the upstroke. Compare it with the relative rear moment arm length of the conventional unit as it passes through these same positions. In the clockwise rotation unit the arc of the tailbearing and the arc of the wrist pin are in the same direction so that the pitman stays almost at 90° to the line through the tailbearing and saddlebearing centers. This gives a uniformly long rear moment arm. Since the geometry of the unit requires the use of a somewhat shorter front working center, the load carried by the pitman is greatly reduced. Since the wrist pin circle is the same diameter as the wrist pin circle of a conventional unit, a pronounced reduction in torque factor is effected. A comparison of torque factors for both units will indicate the magnitude of this reduction.

Note also that the upstroke is not complete until the crank is 17° past its bottom vertical position. So, the upstroke has continued through 197°. This produces a long slow uniform upstroke motion. Since velocity and acceleration are reduced, the peak polished rod load is reduced in proportion. Maximum rod loading will also be reduced and alleviate one of the major limitations of rod pumping, the sucker rods themselves.

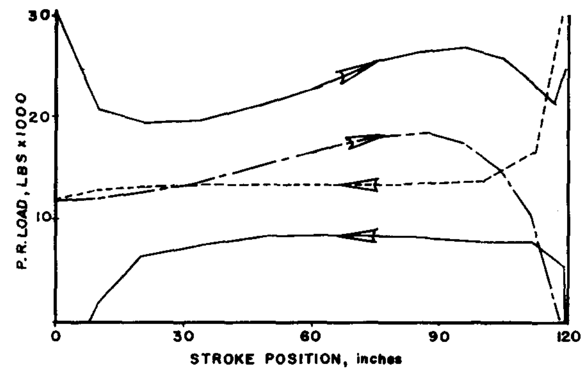
As the upstroke is being completed and counterbalance is moving into position to be lifted again, the rear beam moment arm starts becoming shorter. The resulting torque factor becomes very large and enables the reduced downstroke load to lift a far greater amount of counterbalance weight than would the conventional unit with its smaller torque factor. The overall effects with the special clockwise rotation geometry are that the rear moment arm is long and torque factors are small when upstroke load is being lifted and the unit is doing work, and that the arm becomes short and torque factors are large on the backstroke when counterbalance must be raised into position again by the minimum load.

But it has been shown that torque factors alone do not tell the whole story. The phase relationship of rotary counterbalance is most important since we have seen with permissible load diagrams that a slight out of phase relationship between counterbalance factors and torque factors causes a severe reduction in unit load capacity. Permissible load diagrams must be used to make the complete comparison which should include both load capacity and true counterbalance effect.

To make this comparison we will use the conventional 320-256-120 unit of the previous illustration and a 456-256-120 of identical geometry and compare them with the 320-256G-120 ("Best Geometry") clockwise rotation unit recently developed. Matching counterbalance torques will be used with conventional unit. Counterbalance torque of the special geometry unit will be adjusted to give comparative load capacities.

The preceding permissible load calculations (Tables 3 and 4) and diagrams (Figures 6 and 7) serve to illustrate very clearly the additional capacity available with a certain gear reducer if its power is transmitted to the well through this special geometry. It also serves to show the elimination of enforced negative torques since counterbalance effect does not rise to infinity on either upstroke and downstroke, as it does with conventional geometry.

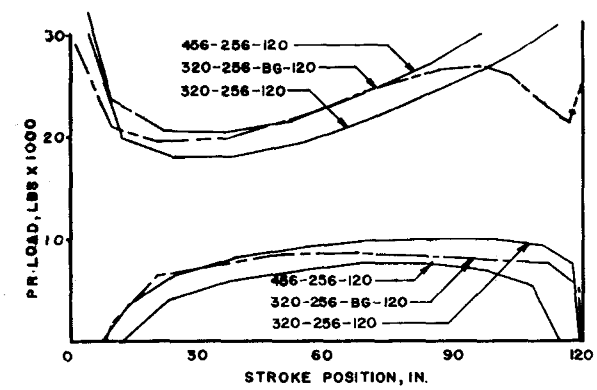
It is also apparent that torque requirements of the prime mover would be greatly reduced since the torque resulting from any given load would not be as large as the torque from the same load with conventional geometry. The uniformity of torque would be greatly increased and the absence of negative torques would also serve to allow reductions in prime mover torque rating. Because of this reduced torque rating and the absence of wide fluctuations in load, the prime mover would operate in an efficiency range which would be better and more efficient. The power or fuel consumption would be reduced in proportion to this difference in average efficiency.



320-256-BG-120 CW ROTATION

16,900 LBS C.B.E.

FIG. 6



UNIT CAPACITY COMPARISON

FIG. 7

TABLE 3.

Permissible Load Calculations
456-256-120 Clockwise Rotation (Figure 7)
Counterbalance Effect 16,000# (1) C.B. Moment = (16,000-200)(56.99) = 900,000"#
(7) Card Length = 5"
Unit Unbalance = + 200#

	(2)		(3)		(4)	(5)	(6)	(7)		(9)
Deg.	C.B. Torque x 1000"#	Unit Torque x1000"#	Torque Available x 1000"#	Torque Factor	Permis. Load x1000#	Per Load - Unit UB (200#)	P.R. Pos %	P.R. Pos. Inches	Act.CB Effect x1000#	CBE + UB x 1000#
0	0	456	456	2.96	154.1	154.3	0000	0	0	.2
15	233.1	456	689.1	18.53	37.1	37.3	.017	.09	12.6	12.8
30	450.0	456	906	38.68	23.4	23.6	.080	.40	11.7	11.9
45	636.3	456	1092.3	53.66	20.4	20.6	.181	.91	11.9	12.1
60	779.4	456	1235.4	61.15	20.2	20.4	.306	1.53	12.7	12.9
75	869.4	456	1325.4	61.51	21.5	21.7	.440	2.20	14.1	14.3
90	(1) 900	456	1356	56.99	23.8	24.0	.569	2.84	15.8	16.0
105	869.4	456	1325.4	49.96	26.5	26.7	.685	3.42	17.4	17.6
120	779.4	456	1235.4	41.99	29.4	29.6	.784	3.92	18.5	18.7
135	636.3	456	1092.3	33.73	32.4	32.6	.866	4.33	18.9	19.1
150	450.0	456	906	25.15	36.0	36.2	.930	4.65	17.9	18.1
165	233.1	456	689.1	15.86	43.4	43.6	.974	4.87	14.7	14.9
180	0	456	456	5.25	86.9	87.1	.997	4.98	0	.2
195	- 233.1	456	222.9	- 7.15	- 31.1	- 30.9	.996	4.98	32.6	32.8
210	- 450.0	456	6	-21.14	- .3	- .1	.965	4.82	21.3	21.5
225	- 636.3	456	- 180.3	-35.34	5.1	5.3	.904	4.52	18.0	18.2
240	- 779.4	456	- 323.4	-47.69	6.8	7.0	.814	4.07	16.0	16.5
255	- 869.4	456	- 413.4	-56.50	7.3	7.5	.700	3.50	15.4	15.6
270	- 900	456	- 444	-61.09	7.3	7.5	.573	2.86	14.7	14.9
285	- 869.4	456	- 413.4	-61.48	6.7	6.9	.439	2.19	14.1	14.3
300	- 779.4	456	- 323.4	-57.87	5.6	5.8	.310	1.55	13.5	13.7
315	- 636.3	456	- 180.3	-50.22	3.6	3.8	.192	.96	12.7	12.9
330	- 450.0	456	- 6	-38.46	.2	.4	.095	.47	11.7	11.9
345	- 233.1	456	222.9	-22.53	- 9.8	- 9.6	.029	.14	10.3	10.5

TABLE 4.

Permissible Load Calculations
320-256-BG-120 Special Clockwise Geometry
Counterbalance Effect 16,900# C.B. Moment = (16,900-2000) (50.47) = 750,000"#
(7) Card Length = 5"
Unit Unbalance = + 2000#

	(2)		(3)		(4)	(5)	(6)	(7)		(9)
Deg.	C.B. Torque x 1000"#	Unit Torque x 1000"#	Torque Available x 1000"#	Torque Factor	Per Load x 1000#	Per Load + 2000# x 1000#	P.R. Pos.	P.R. Pos. Inches	Act. CBE x'1000#	CBE+ 2000# UB
0	0	320	320.0	- 0.18	1777.7	1775.7	.000	0	0	
15	194.3	320	514.3	19.34	26.6	28.6	.021	.105	10.1	12.1
30	375.0	320	695.0	36.70	18.9	20.9	.083	.415	10.2	12.2
45	530.3	320	850.3	48.84	17.4	19.4	.177	.885	10.9	12.9
60	649.5	320	969.5	54.36	17.8	19.8	.290	1.45	11.9	13.9
75	724.5	320	1044.5	54.18	19.3	21.3	.409	2.04	13.4	15.4
90	750.0	320	1070.0	50.47	21.2	23.2	.523	2.62	14.9	16.9
105	724.5	320	1044.5	45.25	23.1	25.1	.628	3.14	16.0	18.0
120	649.5	320	969.5	39.75	24.4	26.4	.720	3.60	16.3	18.3
135	530.3	320	850.3	34.46	24.7	26.7	.801	4.00	15.4	17.4
150	375.0	320	695.0	29.32	23.7	25.7	.870	4.35	12.8	14.8
165	194.3	320	514.3	23.81	21.6	23.6	.928	4.64	8.2	10.2
180	0	320	320	16.71	19.2	21.2	.973	4.87	0	2.0
195	- 194.3	320	125.7	5.55	22.6	24.6	.998	4.99	- 35.0	- 33.0
210	- 375.0	320	- 55.0	- 13.01	4.23	6.23	.991	4.96	28.8	30.8
225	- 530.3	320	- 210.3	- 36.96	5.7	7.7	.937	4.68	14.3	16.3
240	- 649.5	320	- 329.5	- 55.54	5.9	7.9	.835	4.18	11.7	13.7
255	- 724.5	320	- 404.5	- 64.36	6.3	8.3	.703	3.52	11.3	13.3
270	- 750.0	320	- 430.0	- 66.19	6.5	8.5	.560	2.80	11.3	13.3
285	- 724.5	320	- 404.5	- 63.49	6.4	8.4	.418	2.09	11.4	13.4
300	- 649.5	320	- 329.5	- 57.29	5.6	7.6	.286	1.43	11.3	13.3
315	- 530.3	320	- 210.3	- 47.81	4.4	6.4	.171	.855	11.1	13.1
330	- 375.0	320	55.0	- 34.99	1.6	1.6	.080	.400	10.7	12.7
345	- 194.3	320	125.7	- 18.89	6.7	- 4.7	.021	.105	10.3	12.3

SUMMARY

We are able to conclude that conventional units are not and cannot be truly bi-directional. The use of permissible load diagrams prepared from torque factor tables for the specific unit will enable us to determine the unit's true load capacity in each direction of rotation and select the best direction of rotation. Units of different make or geometry of the same API size can be compared and evaluated for true load capacity by the permissible load diagram method. Using this method, we are able to demonstrate the advantages of units designed for a special direction of rotation.