Methods for Improved Utilization of Beam Pumping Units

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INTRODUCTION

In the past decade the number of secondary recovery projects has increased rapidly in the Permian Basin and surrounding area. Water injection is the most popular method of re-energizing reservoirs. As a result, demands on the artificial lift equipment have increased due to higher individual well productivity. In many instances larger equipment has been installed.

Two major reasons for replacing beam equipment in the past have been torque limitations and displacement limitations. Torque limits are usually reached prematurely because the unit is being operated in the longest stroke. Displacement limits are usually defined by an arbitrarily established maximum operating speed. As a result equipment is replaced when, with some modification, it could well have met the increased demands for a prolonged period.

The slow, long-stroke pumping method is considered the best method for trouble-free operation of beam units. In the past, operators were able to employ this method because allowables were low and most fields were under primary recovery. As a result, lift equipment was not loaded.

Now, with allowable factors up and secondary recovery projects responding, demands placed on lift equipment have increased significantly. Since producing wells are predominately equipped with beam units, any improvement in the loading efficiency of these units could result in substantial savings through delayed or unnecessary investment for larger units. One way to achieve this improvement is through the use of the fast, short-stroke pumping method, when applicable. Another way is by controlled overloading of existing equipment.

GEAR BOX LIMITATIONS

The fast, short-stroke pumping method can improve the efficiency of a unit by producing more fluid with a given size gear box and should be considered when additional capacity is needed prior to purchasing a larger unit. Figures 1a, 1b and 1c demonstrate the ability of the fast, short-stroke method to outproduce the slow, long-stroke method with a given size gear box. Figure 1a is a plot of Peak Torque versus Polished Rod Velocity for 64-in., 74-in. and 86-in. stroke lengths. (These stroke lengths are normally available on API 228,000 in.-lb units.) Calculations were made using the design method presented in API RP 11L. This figure demonstrates that at the same polished rod speed, the longer strokes result in higher torque values. Figure 1b is a plot of Production versus Polished Rod Speed and demonstrates that production varies directly as the polished rod speed. Figure 1c is a plot of Production versus Peak Torque at various polished rod speeds and stroke lengths. If the gear box limitation were 250,000 in.-lb, this figure indicates that 465 BPD can be produced with the 64-in. stroke as opposed to 325 BPD with a 74-in. stroke and 240 BPD with an 86-in. stroke.

Figures 2a, 2b and 2c are similar plots with 86-in., 100-in., 120-in. and 144-in. stroke lengths. (These stroke lengths are normally available with 320,000 and 456,000 in.-lb units.) As before, considering the gear box alone as the limiting factor, more production can be realized in the shorter strokes.

CRITICAL SPEED

A factor to consider when designing rod pump installations is the critical speed. Critical speed, for the purpose of this memo, is defined as the speed at which the minimum load on the polished rod approaches zero. This is the speed at which the carrier bar is about to leave the polished rod clamp.

Using the available computer program (M6036) to make the necessary calculations, critical speeds for various stroke lengths, plunger sizes and depths were determined. Table 1 shows the results of these calculations.

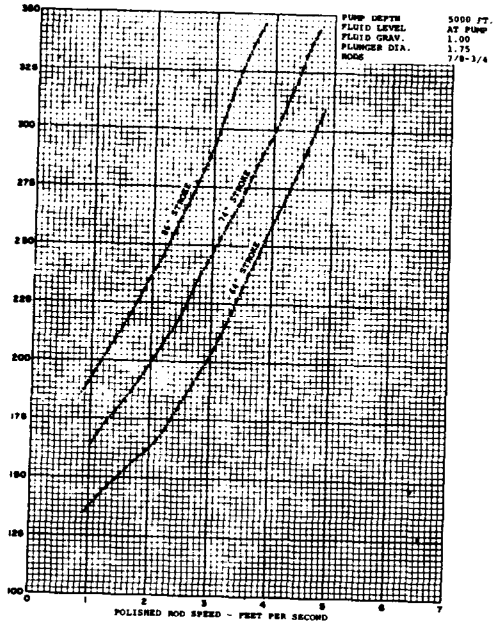

FIGURE 1A

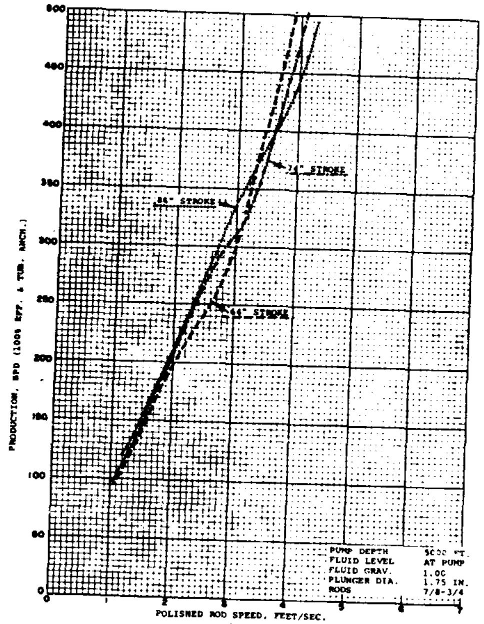

FIGURE 1B

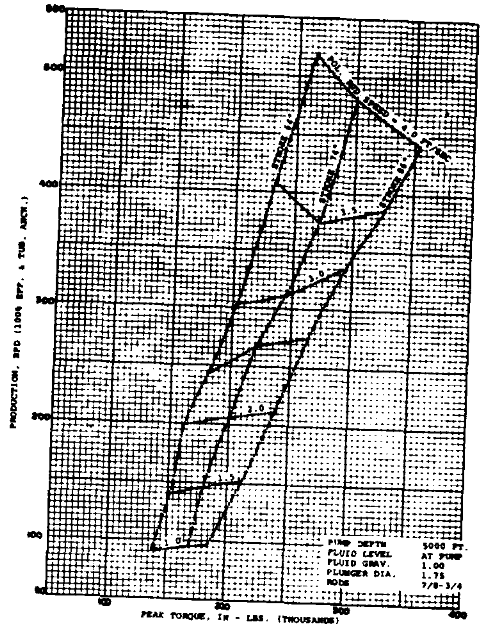

FIGURE 1C

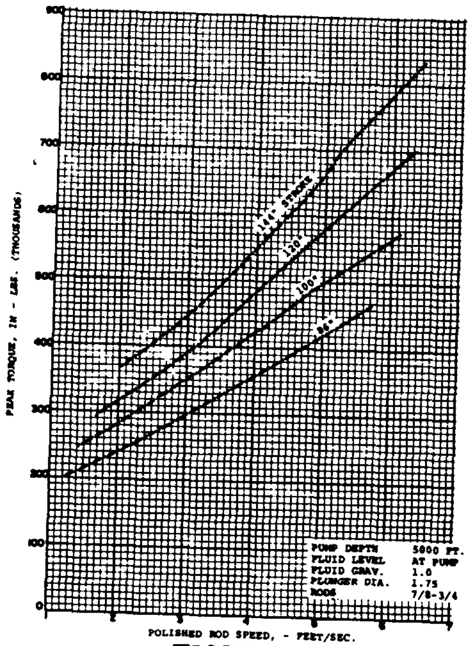

FIGURE 2A

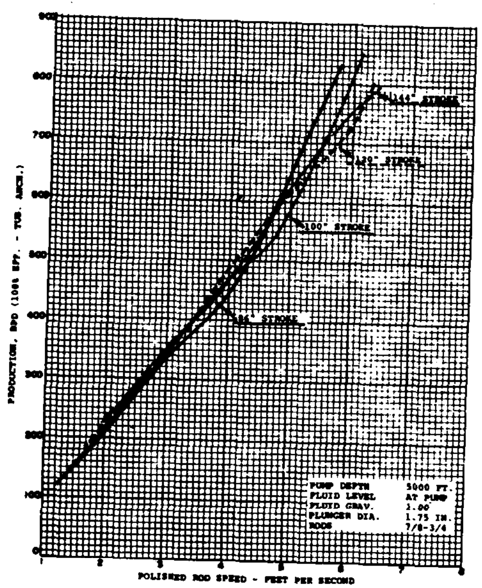

FIGURE 2B

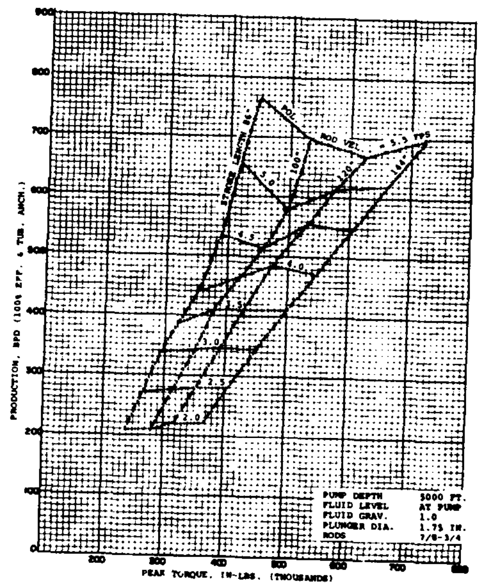

FIGURE 2C

TABLE 1
CRITICAL PUMPING SPEEDS

Stroke Length - In.	Pumping Depth - Ft	SPM @ Various Plunger Sizes 1.50 In.	1.75 In.	2.00 In.
48	3000	30	30	30
54	3000	28	28	27.5
64	3000	-	25	24.5
74	3000	-	23	22.5
86	3000	-	-	20.5
74	5000	26.6	27	27.3*
86	5000	24.6	24.6	24.7
100	5000	22.5	22.1	22.2
120	5000	19.4	19.2	19.2
144	5000	16.7	16.8	16.8

*Projected

The effect of the plunger size appears to be minimal. This may be somewhat misleading since the calculations do not consider pump friction. The table also indicates that the critical speed is faster for the shorter stroke lengths, and that for the same stroke length the critical speed increases as the pump setting depth increases. Actually, for the latter circumstance the major factor is the rod weight. Figures 3a through 3h show graphically the effects of plunger size, stroke length and depth on the critical speed. These Figs. and Table 1 are presented to emphasize the point that critical speeds are greater than normally anticipated. In the great majority of cases, some other design parameter will limit the design before the critical speed is approached.

OTHER DESIGN LIMITATIONS

Other parameters to consider when designing pumping installations are peak load and rod stress.

TABLE 2a
PRODUCTION LIMITATIONS - BPD

NO.	PARAMETERS	PROD. IN BPD @ VARIOUS STROKE LENGTHS 64"	74"	86"	100"	120"	144"
1	Critical Speed	-	-	830	850	820	820
2	Allow. Rod Stress - GR. C	227	284	290	311	343	320
3	Allow. Rod Stress - GR. D	421	415	418	458	485	526
4	Peak Torque-250,000 In.-Lb	465	325	240	160	-	-
5	Peak Torque-350,000 In.-Lb	-	-	430	345	280	-
6	Peak Torque-500,000 In.-Lb	-	-	-	585	512	415

TABLE 2b
PRODUCTION LIMITATIONS - BPD

PARAMETER COMB. (2a ABOVE)	PROD. IN BPD @ VARIOUS STROKE LENGTHS 64"	74"	86"	100"	120"	144"
1, 2 & 4	227	284	240	160	-	-
1, 2 & 5	227	284	290	311	280	-
1, 2 & 6	227	284	290	311	343	320
1, 3 & 4	421	325	240	160	-	-
1, 3 & 5	421	415	418	345	280	-
1, 3 & 6	421	415	418	458	485	415

NOTE: Tables 2a & 2b are based on 1.75-in. pump operating @ 100 percent efficiency, 7/8 & 3/4 standard rod taper, 5000-ft pump setting depth with the fluid level at the pump and a fluid gravity of 1.0.

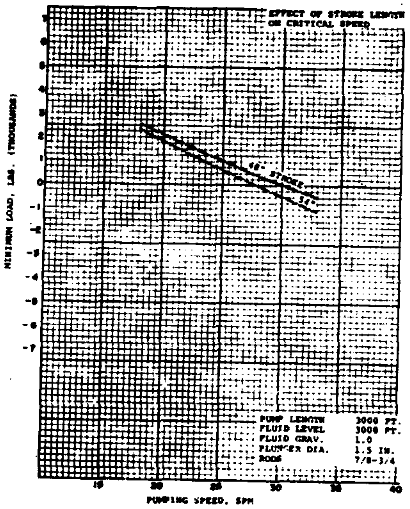

FIGURE 3A

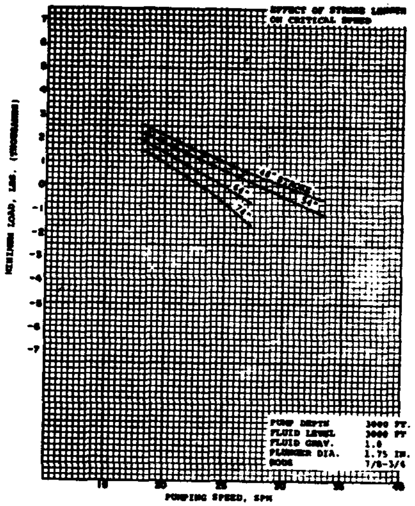

FIGURE 3B

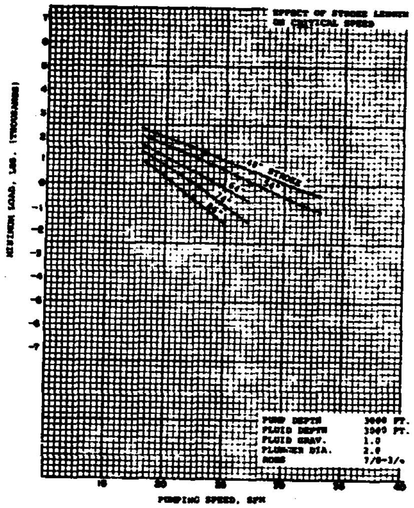

FIGURE 3C

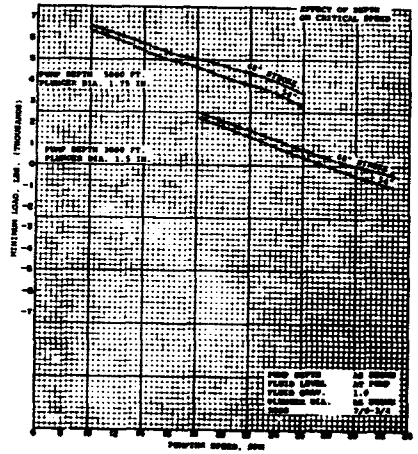

FIGURE 3D

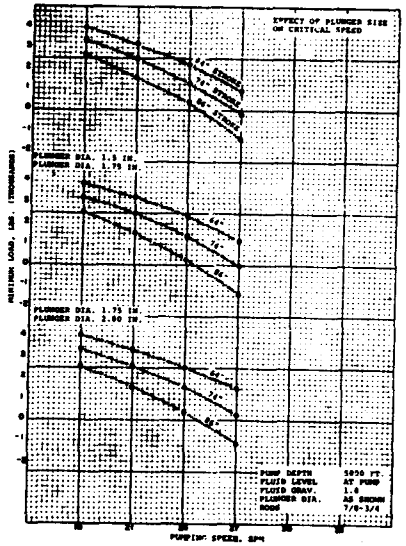

FIGURE 3E

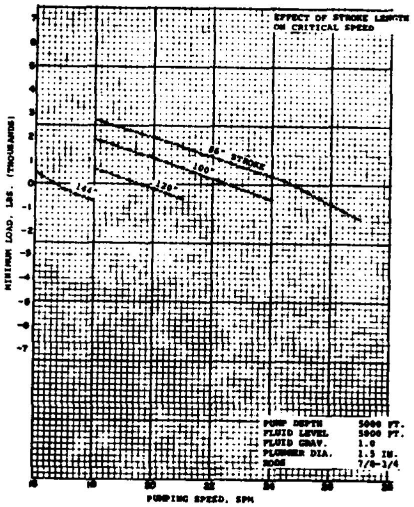

FIGURE 3F

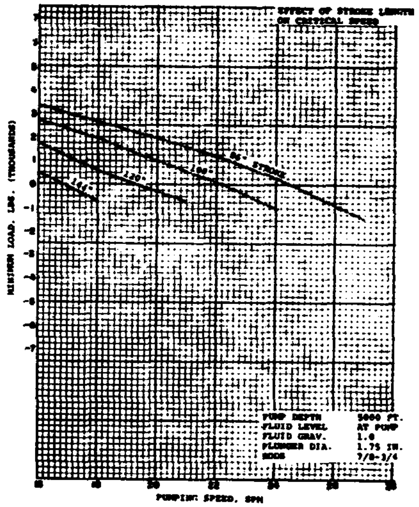

FIGURE 3G

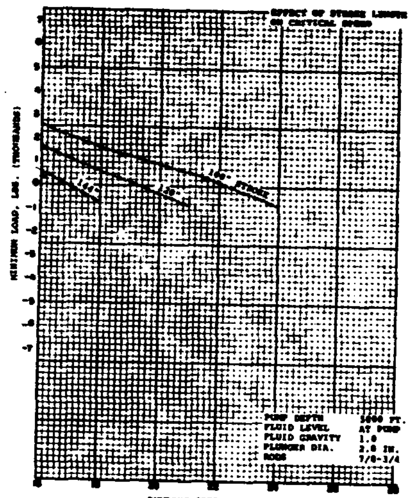

FIGURE 3H

The allowable rod stress depends primarily on the grade rod and the minimum load. Peak load is limited by the beam rating. All parameters should be considered when establishing the most efficient operating conditions for an installation. Tables 2a and 2b demonstrate the production limitations imposed by the different parameters.

In some cases in the example shown, the limiting parameter is set by the gear box while in others by the rod stress. The critical speed was never the limiting parameter.

A study was recently made to aid in recommending maximum safe operating conditions for the existing 80,000 and 114,000 in.-lb units in a shallow West Texas Water Flood Project. Available stroke lengths from 25 in. through 54 in. and pump sizes of 1.25 in., 1.5 in., and 1.75 in. were considered. Rod strings of 100 percent ⅞ and 100 percent ¾, as well as the standard ⅞-¾ tapered strings were used. Parameter limitations used were: (1) peak torque of 1.25 times the gear box rating; (2) allowable rod stress for Grade C rods; and (3) maximum load range of 70 percent. A maximum production of 202 BPD @ 80 percent efficiency was calculated for a ⅞-¾ tapered rod string and 1.75-in. pump operating at twenty-five 32-in. strokes per minute. In the application, the fast, short-stroke pumping method was the more efficient.

OVERLOADING

Overloading of equipment, as a general practice, is not recommended. In some instances overloading can be justified. An example would be overloading an existing beam unit for a short period (less than a month) to get an increased capacity test. Another example would be overloading of a beam unit on a responding waterflood well. The unit may have no value other than salvage and would be little or no loss if it failed.

In the former case, the short test period, the beam and structural members and the reducer may be overloaded by a factor of two with no damage, provided the gears and bearings are in good condition and properly lubricated. Shock loads, such as occur in a pump-off condition would be very detrimental and must be avoided.

In the latter permanent overload case, additional limitations are involved. As well as checking the condition of the bearings, gears and gear lubricant, it is recommended that an EP lubricant be used, if not already in service. Neither the reducer nor the beam and other structural members should be overloaded in excess of 25 percent. The gear lubricant should be inspected monthly for contaminants and changed if necessary. Shock loads must be avoided. Counterbalancing should be checked often and the proper counterbalance maintained.

Perhaps the most critical item in reducer life is the lubricant film on the gear teeth. If this film breaks down and wear, caused by metal-to-metal contact, occurs, the life expectancy of the gears is reduced. This is the case whether the reducer is overloaded or not. The decrease in life expectancy would be proportional to the amount of load applied. If the lubricant film can be maintained, it does not seem unreasonable to anticipate that the reducer could be 50 percent overloaded and still have an almost normal life expectancy.

One company has had some actual experience with deliberate overloading. Results were good. An overload of 50 percent was applied to a group of approximately fifty 57,000 in.-lb units. In a few cases the overload reached 75 percent. Only one gear box failure occurred over a seven-year period. These good results were attributed to maintaining proper counterbalance and a strong preventive maintenance program particularly with respect to gear box lubricant.

OTHER FACTORS

Other aids for better utilization of existing units are also available. Extra high slip motors have proven beneficial by reducing load ranges. This reduction in load range will not only benefit the gear box but should prolong rod life. To receive full benefit from the extra high slip motors, the motors must be loaded.

The use of sinker bars on the bottom of rod strings is another aid. This added weight will reduce compressive forces in the lower part of the string.

A minimum pump submergence should be maintained to achieve higher pump efficiencies. Submergence should be limited to a depth that assures satisfactory pump filling. This is done to keep the pressure around the pump intake low which permits the dissolved gas to come out of solution prior to reaching the pump and permits it to be produced in the annulus rather than through the pump. A properly designed gas anchor is imperative under these circumstances. Another advantage in setting the pump as high as practical is the reduction in rod weight.

TABLE 3
WELLS OPERATING AT HIGH SPEED

Lease & Well No.	Approx. Pump Depth Ft	Speed SPM	Speed Ft/Sec.	Stroke Length In.
Mary Foster No. 99	2500	16	3.29	74
Mary Foster No. 102	2500	16.5	3.39	74
Chalk Estate No. 7	1800	19	2.53	48
Chalk Estate No. 10	1800	19.5	1.95	36
Owen Chalk No. 14	1800	20	2.33	42
Owen Chalk No. 24	2600	20	1.50	27
Sloan Chalk No. 11	1800	17.4	2.32	48
A. E. O'Daniel No. 4	2800	20.4	3.06	54
A. E. O'Daniel No. 8	2800	21	2.33	40
A. E. O'Daniel No. 13	2800	17	3.49	74
Fasken FA No. 1	2800	13	4.48	124
SLSA Unit No. 61	4400	20	2.67	48
SLSA Unit No. 118	4400	18	2.70	54
SLSA Unit No. 138	4400	18	3.20	64
SLSA Unit No. 181	4400	14	3.89	100
SLSA Unit No. 206	4400	20	1.89	34
McFarland Queen Unit No. 5	4700	12	4.00	120
McFarland Queen Unit No. 11	4700	14	3.34	86
McFarland Queen Unit No. 14	4700	14	3.34	86
McFarland Queen Unit No. 17	4700	14	3.34	86
McFarland Queen Unit No. 48	4700	15.5	3.70	86
McFarland Queen Unit No. 58	4700	16.5	3.94	86
McFarland Queen Unit No. 64	4700	14	3.89	100

FIELD EXPERIENCE

An informal survey of operating personnel as to their experience with high operating speeds was conducted. High speeds, for the purposes of this survey, were arbitrarily defined as those at or above 50 percent of the free-fall rate of the rods (based on furnished tabular data) or at 20 SPM or greater, whichever was the lesser.

Table 3 shows some examples of wells operating at higher speeds.

The general opinion of the personnel operating these wells was that the high speed operations were not causing any significant problems and that with conditions favorable, high speed operations are satisfactory. One foreman noted that he had experienced less trouble with high-speed small-pump installations than with slow-speed large-pump installations. Generally, all foremen agreed that slow, long-stroke operations are preferred over fast, short-stroke operations.

COMPUTER PROGRAMS

There are available to Mobil personnel two computer programs to facilitate designing and evaluating beam pumping installations. The first program (M6036) performs the design calculations for sucker rod pumping systems for conventional units as set out in API RP 11L. The program is very versatile. One input card can result in from 1 to 40,000 lines of output, each line being a different design condition. Figures 4, 5, 6 and 7 are examples of input and output from this program. Required input is fluid level, pump setting depth, pumping speeds, stroke lengths, plunger diameters, specific gravity of the fluid, tubing size and rod sizes. From 1 to 40 SPM, up to six different stroke lengths, up to 17 different standard rod strings and up to 10 different plunger sizes can be evaluated with one input card. Nonstandard rod tapers can be handled by the program, but additional input is required. This additional input consists of the percentage of each size rod used in the string and the frequency factor for the non-standard string. These non-standard frequency factors can be estimated from Supplement 1 to API RP 11L.

Some additional features of the program are that output can be limited to fall into a specified range of production and/or below a specified peak torque value. If desired the nondimensional variables, Fo/Skr, N/No and N/No′ will be printed following the data line to which these variables pertain.

In addition to input information, output consists of production at 100 percent efficiency with tubing anchored and unanchored, peak rod load, minimum rod load, counterbalance effect, peak torque, footages of each size rod in the string, polished rod horsepower, motor ratings, allowable stresses for C and D rods and the calculated peak stress on the top rod. Allowable rod stresses are calculated as recommended in API Standard 11B (16th Edition) Supplement 2 issued April, 1968. For C rods, a minimum tensile of 90,000 psi is used in the calculation, while for D rods, 110,000 psi is used. A safety factor of 1.0 is used in both calculations.

The program is well-suited for the design of new installations. The designer is presented with a large number of conditions from which to make the proper selection for the installation under consideration. It can also be useful for evaluating an existing installation. By plugging in the actual conditions, the loads and the nondimensional variables can be output. The shape of an actual dynamometer card can be compared with a "normal" dynagraph in API Bulletin 11L2 having similar nondimensional variables. If the cards are similar in shape, the well is performing normally. If the cards are not similar, the system needs further investigation.

The second program (M6046) calculates torque factors, polished rod positions and permissible loads at specified crank angles and plots a permissible load diagram at a specified load and stroke scale for conventional, air balance and Mark II type beam pumping units. If the plot has the same scale as a dynamometer card, the two can be overlayed and a quick glance can tell whether the gear box rating is being exceeded. Figures 8 through 16 are examples of output from this program. Input required for calculating well load and counterbalance torque factors and polished rod position consists of certain unit dimensions, crank angles, type of unit and direction of rotation. Additional input required to calculate permissible

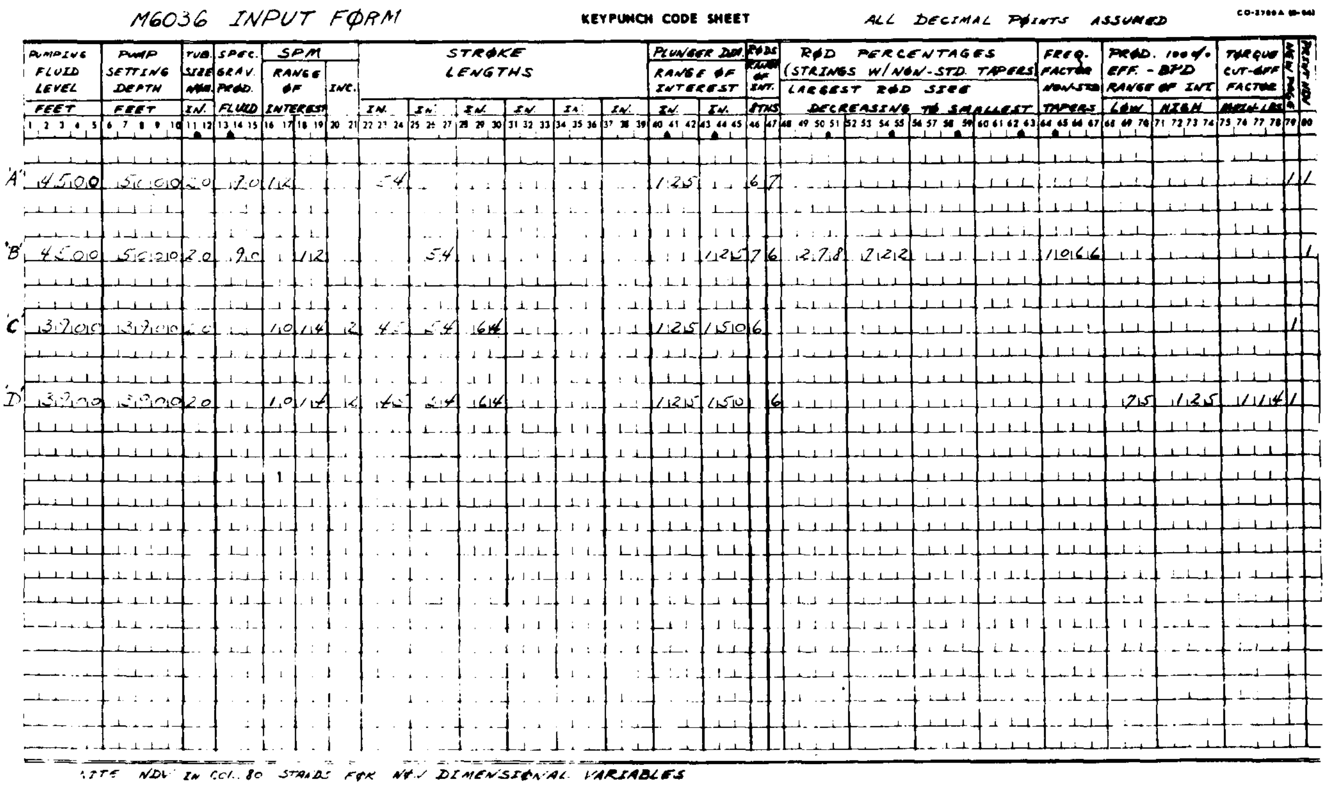

FIGURE 4

M6036 DESIGN CALCULATIONS FOR SUCKER ROD PUMPING SYSTEMS
(CONVENTIONAL UNITS)
BASED ON API RP 11L

	PUMP SET. DEPTH FEET	PUMP. FLUID LEVEL FEET	TUB DIA NOM IN.	SPEC GRAV PROD FLD.	PUMP BORE IN.	LGH OF STR IN.	S P M	PROD.(100 PCT. EFF) TUB. ANCH BPD	TUB. UNAN BPD	PEAK ROD LOAD MLBS	MIN. ROD LOAD MLBS	CB EFF. MLBS	PEAK TORQ M*IN LBS.	ROD FOOTAGES 9/8 IN.	8/8 IN.	7/8 IN.	6/8 IN.	5/8 IN.	4/8 IN.	POL ROD HP	HI SLP MTR SZ.	KOF MTR RTG HP	ROD STRESSES MPSI ALLOW. API C	API D	PEAK CALC.
'A'	5000	4500	2.0	0.90	1.25	54	12	111	104	11.4	5.5	8.8	97	0	0	0	5000	0	0	4.3	1	10.0	29.6	34.6	25.8
	*** NON-DIMENSIONAL VARIABLES FOR PRECEDING DATA LINE ARE FO/SKR=0.17 N/NO=0.24 N/NO'=0.24																								
'A'	5000	4500	2.0	0.90	1.25	54	12	112	105	12.2	6.2	9.6	101	0	0	1390	3610	0	0	4.3	1	10.0	28.3	33.3	20.3
	*** NON-DIMENSIONAL VARIABLES FOR PRECEDING DATA LINE ARE FO/SKR=0.16 N/NO=0.24 N/NO'=0.22																								
'A'	5000	4500	2.0	0.90	1.25	54	12	117	109	14.6	7.7	11.6	117	0	0	5000	0	0	0	4.9	1	10.0	29.7	34.7	24.3
	*** NON-DIMENSIONAL VARIABLES FOR PRECEDING DATA LINE ARE FO/SKR=0.12 N/NO=0.24 N/NO'=0.24																								
'B'	5000	4500	2.0	0.90	1.25	54	12	112	105	12.2	6.2	9.6	101	0	0	1390	3610	0	0	4.3	1	10.0	28.3	33.3	0.0
	*** NON-DIMENSIONAL VARIABLES FOR PRECEDING DATA LINE ARE FO/SKR=0.16 N/NO=0.24 N/NO'=0.22																								

ZEROES IN HI SLIP AND/OR KOF MOTOR COLS. OF OUTPUT INDICATE HP REQUIREMENTS EXCEED PROGRAM LIMITATIONS
ZERO IN PEAK CALC. ROD STRESS COL. INDICATES ROD PERCENTAGES AND FREQ. FACTOR WERE INPUT--ROD TAPER MAY BE NON-STD.

FIGURE 5

M6036 DESIGN CALCULATIONS FOR SUCKER ROD PUMPING SYSTEMS
(CONVENTIONAL UNITS)
BASED ON API RP 11L

PUMP SET. DEPTH FEET	PUMP. FLUID LEVEL FEET	TUB DIA NOM IN.	SPEC GRAV PROD FLD.	PUMP BORE IN.	LGH OF STR IN.	S P M	PROD.(100 PCT. EFF) TUB. ANCH BPD	TUB. UNAN BPD	PEAK ROD LOAD MLBS	MIN. ROD LOAD MLBS	CB EFF. MLBS	PEAK TORQ M*IN LBS.	ROD FOOTAGES 9/8 IN.	8/8 IN.	7/8 IN.	6/8 IN.	5/8 IN.	4/8 IN.	POL ROD HP	HI SLP MTR SZ.	KOF MTR RTG HP	ROD STRESSES MPSI ALLOW. API C	API D	PEAK CALC.
3900	3900	2.0	1.00	1.25	45	10	73	69	8.9	4.6	7.0	61	0	0	0	3900	0	0	2.5	1	5.0	28.4	~~33.4~~	~~20.2~~
3900	3900	2.0	1.00	1.50	45	10	98	89	9.9	4.5	7.5	74	0	0	0	3900	0	0	3.1	1	7.5	28.2	33.2	22.3
3900	3900	2.0	1.00	1.25	54	10	90	86	9.1	4.6	7.0	75	0	0	0	3900	0	0	3.2	1	7.5	28.3	33.3	20.6
3900	3900	2.0	1.00	1.50	54	10	123	114	10.1	4.4	7.5	95	0	0	0	3900	0	0	4.0	1	10.0	28.1	33.1	22.9
3900	3900	2.0	1.00	1.25	64	10	109	105	9.3	4.4	7.0	93	0	0	0	3900	0	0	4.1	1	7.5	28.2	33.2	21.1
3900	3900	2.0	1.00	1.50	64	10	150	141	10.4	4.3	7.5	117	0	0	0	3900	0	0	5.1	2	10.0	27.9	32.9	23.4
3900	3900	2.0	1.00	1.25	45	12	89	84	9.2	4.3	7.0	68	0	0	0	3900	0	0	3.1	1	7.5	28.0	33.0	20.8
3900	3900	2.0	1.00	1.50	45	12	121	110	10.1	4.1	7.5	80	0	0	0	3900	0	0	3.9	1	10.0	27.8	32.8	22.9
3900	3900	2.0	1.00	1.25	54	12	110	105	9.4	4.2	7.0	85	0	0	0	3900	0	0	4.0	1	7.5	27.8	32.8	21.3
3900	3900	2.0	1.00	1.50	54	12	150	139	10.4	4.0	7.5	105	0	0	0	3900	0	0	5.0	2	10.0	27.6	32.6	23.6
3900	3900	2.0	1.00	1.25	64	12	133	127	9.7	4.0	7.0	107	0	0	0	3900	0	0	5.2	1	10.0	27.6	~~32.6~~	~~22.0~~
3900	3900	2.0	1.00	1.50	64	12	183	172	10.7	3.8	7.5	131	0	0	0	3900	0	0	6.4	2	15.0	27.3	32.3	24.3
3900	3900	2.0	1.00	1.25	45	14	107	101	9.5	4.0	7.0	75	0	0	0	3900	0	0	3.9	1	7.5	27.6	32.6	21.5
3900	3900	2.0	1.00	1.50	45	14	145	132	10.4	3.8	7.5	86	0	0	0	3900	0	0	4.8	2	10.0	27.4	32.4	23.6
3900	3900	2.0	1.00	1.25	54	14	132	125	9.8	3.8	7.0	95	0	0	0	3900	0	0	5.1	1	7.5	27.3	32.3	22.2
3900	3900	2.0	1.00	1.50	54	14	180	167	10.8	3.6	7.5	115	0	0	0	3900	0	0	6.3	2	15.0	27.1	~~32.1~~	~~24.4~~
3900	3900	2.0	1.00	1.25	64	14	159	152	10.2	3.5	7.0	121	0	0	0	3900	0	0	6.6	2	10.0	27.0	32.0	23.1
3900	3900	2.0	1.00	1.50	64	14	219	206	11.2	3.4	7.5	145	0	0	0	3900	0	0	8.0	2	15.0	26.8	31.8	25.3

ZEROES IN HI SLIP AND/OR KOF MOTOR COLS. OF OUTPUT INDICATE HP REQUIREMENTS EXCEED PROGRAM LIMITATIONS
ZERO IN PEAK CALC. ROD STRESS COL. INDICATES ROD PERCENTAGES AND FREQ. FACTOR WERE INPUT--ROD TAPER MAY BE NON-STD.

FIGURE 6

M6036 DESIGN CALCULATIONS FOR SUCKER ROD PUMPING SYSTEMS
(CONVENTIONAL UNITS)
BASED ON API RP 11L

PUMP SET. DEPTH FEET	PUMP. FLUID LEVEL FEET	TUB DIA NOM IN.	SPEC GRAV PROD FLD.	PUMP BORE IN.	LGH OF STR IN.	S P M	PROD.(100 PCT. EFF) TUB. ANCH BPD	TUB. UNAN BPD	PEAK ROD LOAD MLBS	MIN. ROD LOAD MLBS	CB EFF. MLBS	PEAK TORQ M*IN LBS.	ROD FOOTAGES 9/8 IN.	8/8 IN.	7/8 IN.	6/8 IN.	5/8 IN.	4/8 IN.	POL ROD HP	HI SLP MTR SZ.	KOF MTR RTG HP	ROD STRESSES MPSI ALLOW. API C	API D	PEAK CALC.
3900	3900	2.0	1.00	1.50	45	10	98	89	9.9	4.5	7.5	74	0	0	0	3900	0	0	3.1	1	~~7.5~~	~~28.2~~	~~33.2~~	~~22.3~~
3900	3900	2.0	1.00	1.25	54	10	90	86	9.1	4.6	7.0	75	0	0	0	3900	0	0	3.2	1	7.5	28.3	33.3	20.6
3900	3900	2.0	1.00	1.50	54	10	123	114	10.1	4.4	7.5	95	0	0	0	3900	0	0	4.0	1	10.0	28.1	33.1	22.9
3900	3900	2.0	1.00	1.25	64	10	109	105	9.3	4.4	7.0	93	0	0	0	3900	0	0	4.1	1	7.5	28.2	33.2	21.1
3900	3900	2.0	1.00	1.25	45	12	89	84	9.2	4.3	7.0	68	0	0	0	3900	0	0	3.1	1	7.5	28.0	33.0	~~20.8~~
3900	3900	2.0	1.00	1.50	45	12	121	110	10.1	4.1	7.5	80	0	0	0	3900	0	0	3.9	1	~~10.0~~	~~27.8~~	~~32.8~~	~~22.9~~
3900	3900	2.0	1.00	1.25	54	12	110	105	9.4	4.2	7.0	85	0	0	0	3900	0	0	4.0	1	7.5	27.8	32.8	21.3
3900	3900	2.0	1.00	1.25	45	14	107	101	9.5	4.0	7.0	75	0	0	0	3900	0	0	3.9	1	7.5	27.6	32.6	21.5

ZEROES IN HI SLIP AND/OR KOF MOTOR COLS. OF OUTPUT INDICATE HP REQUIREMENTS EXCEED PROGRAM LIMITATIONS
ZERO IN PEAK CALC. ROD STRESS COL. INDICATES ROD PERCENTAGES AND FREQ. FACTOR WERE INPUT--ROD TAPER MAY BE NON-STD.

FIGURE 7

PROGRAM NO. M6046 - TORQUE FACTOR CALCULATIONS
TYPE -1 UNIT TEST 2/23/71

UNIT TYPE AND ROTATION	SLOW SPEED SHAFT TO CRANK BEARING (IN.)	SLOW SPEED SHAFT TO SADDLE BEARING (IN.)	SADDLE BEARING TO TAIL BEARING (IN.)	CRANK BEARING TO TAIL BEARING (IN.)	SADDLE BEARING TO POLISHED ROD (IN.)
-1.	27.00	155.83	96.00	122.25	96.00

SLOW SPEED SHAFT TO SADDLE BEARING VERTICAL DISTANCE = 122.75 IN. HORIZONTAL DISTANCE = 96.00 IN.

STROKE LENGTH = 54.78 IN. CRANK ANGLE SHIFT = 141.9 DEGREES

CRANK ANGLE (DEGREES)	POLISHED ROD POSITION (FRACTION OF STROKE)	WELL LOAD TORQUE FACTOR	COUNTERBALANCE TORQUE FACTOR
15	0.0248	9.3196	0.2588
30	0.0872	16.5259	0.5000
45	0.1800	22.0340	0.7071
60	0.2948	25.6717	0.8660
75	0.4224	27.4012	0.9659
90	0.5537	27.2460	1.0000
105	0.6799	25.2820	0.9659
120	0.7927	21.6829	0.8660
135	0.8850	16.7744	0.7071
150	0.9517	11.0335	0.5000
165	0.9900	4.9855	0.2588
180	0.9996	-0.9416	0.0000
195	0.9816	-6.5075	-0.2588
210	0.9381	-11.6381	-0.4999
225	0.8711	-16.3350	-0.7071
240	0.7827	-20.5674	-0.8660
255	0.6755	-24.1756	-0.9659
270	0.5532	-26.7969	-1.0000
285	0.4218	-27.8554	-0.9659
300	0.2905	-26.6854	-0.8660
315	0.1711	-22.8276	-0.7071
330	0.0765	-16.3764	-0.5000
345	0.0175	-8.0958	-0.2588
360	0.0001	0.6460	-0.0000

FIGURE 8

PROGRAM NO. M6046 - TORQUE FACTOR CALCULATIONS
TYPE -1 UNIT TEST 2/23/71

UNIT TYPE AND ROTATION	SLOW SPEED SHAFT TO CRANK BEARING (IN.)	SLOW SPEED SHAFT TO SADDLE BEARING (IN.)	SADDLE BEARING TO TAIL BEARING (IN.)	CRANK BEARING TO TAIL BEARING (IN.)	SADDLE BEARING TO POLISHED ROD (IN.)
-1.	27.00	155.83	96.00	122.25	96.00

SLOW SPEED SHAFT TO SADDLE BEARING VERTICAL DISTANCE = 122.75 IN. HORIZONTAL DISTANCE = 96.00 IN.

STROKE LENGTH = 54.78 IN. CRANK ANGLE SHIFT = 141.9 DEGREES

CRANK ANGLE (DEGREES)	POLISHED ROD POSITION (FRACTION OF STROKE)	POLISHED ROD POSITION (IN. FROM BOTTOM OF STROKE)	PERMISSIBLE LOAD (LBS.)
15	0.0248	1.361	53103.
30	0.0872	4.778	27015.
45	0.1800	9.865	25629.
60	0.2948	16.151	25525.
75	0.4224	23.140	25985.
90	0.5537	30.334	26836.
105	0.6799	37.248	28138.
120	0.7927	43.428	30165.
135	0.8850	48.486	33570.
150	0.9517	52.140	40314.
165	0.9900	54.237	61620.
180	0.9996	54.760	-169621.
195	0.9816	53.776	-1895.
210	0.9381	51.391	10739.
225	0.8711	47.720	14876.
240	0.7827	42.878	16226.
255	0.6755	37.005	16176.
270	0.5532	30.306	15339.
285	0.4218	23.110	14078.
300	0.2905	15.916	12575.
315	0.1711	9.374	10730.
330	0.0765	4.192	7719.
345	0.0175	0.960	-1464.
360	0.0001	0.010	189419.

PEAK TORQUE	MAX. CB MOMENT	STRUCTURAL UNBALANCE
160000. IN.-LBS.	563000. IN.-LBS.	300. LBS.

FIGURE 9

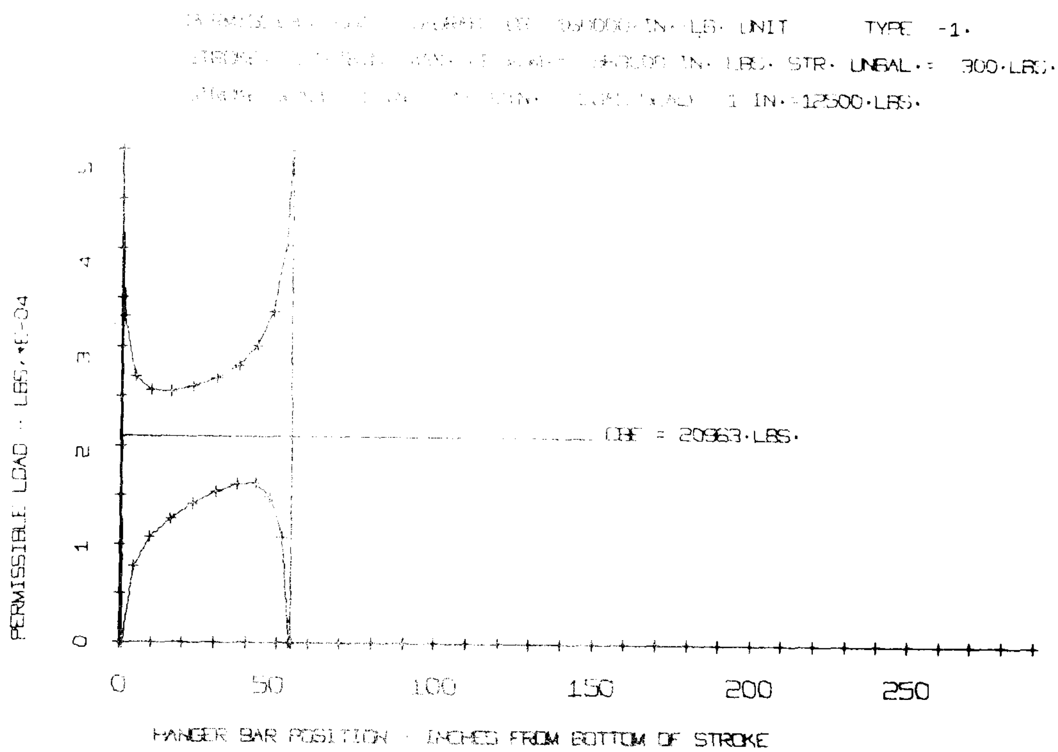

FIGURE 10

TYPE #2 UNIT TEST

PROGRAM NO. MOO43 - TORQUE FACTOR CALCULATIONS

UNIT TYPE AND ROTATION	SLOW SPEED SHAFT TO CRANK BEARING (IN.)	SLOW SPEED SHAFT TO TAIL BEARING (IN.)	PITMAN BEARING TO TAIL BEARING (IN.)	CRANK BEARING TO PITMAN BEARING (IN.)	TAIL BEARING TO POLISHED ROD (IN.)
2.	15.25	123.69	50.00	114.00	120.00

SLOW SPEED SHAFT TO TAIL BEARING VERTICAL DISTANCE = 114.00 IN. HORIZONTAL DISTANCE = 48.00 IN.

STROKE LENGTH = 74.38 IN. CRANK ANGLE SHIFT = 157.1 DEGREES

CRANK ANGLE (DEGREES)	POLISHED ROD POSITION (FRACTION OF STROKE)	WELL LOAD TORQUE FACTOR	COUNTERBALANCE TORQUE FACTOR
15	0.9803	-11.2382	-7.2580
30	0.9220	-21.6347	-13.9724
45	0.8307	-29.8110	-19.2529
60	0.7157	-35.0079	-22.6093
75	0.5879	-37.1055	-23.9640
90	0.4577	-36.4664	-23.5512
105	0.3338	-33.6435	-21.7281
120	0.2228	-29.1459	-18.8234
135	0.1301	-23.3356	-15.0709
150	0.0599	-16.4380	-10.6162
165	0.0155	-8.6246	-5.5700
160	0.0000	-0.1288	-0.0832
195	0.0149	8.6553	5.5899
210	0.0606	17.1538	11.0785
225	0.1346	24.7100	15.9585
240	0.2327	30.7296	19.8462
255	0.3486	34.7956	22.4721
270	0.4750	36.6707	23.6832
285	0.6040	36.2369	23.4029
300	0.7273	33.4318	21.5914
315	0.8365	28.2327	18.2336
330	0.9233	20.7064	13.3729
345	0.9799	11.1284	7.1870
360	0.9999	0.1285	0.0830

TAIL BEARING TO AIR CYL. BEARING 77.50 IN.

FIGURE 11

PROGRAM NO. M6046 - TORQUE FACTOR CALCULATIONS

TYPE +2 UNIT TEST 2/23/71

UNIT TYPE AND ROTATION	SLOW SPEED SHAFT TO CRANK BEARING (IN.)	SLOW SPEED SHAFT TO TAIL BEARING (IN.)	PITMAN BEARING TO TAIL BEARING (IN.)	CRANK BEARING TO PITMAN BEARING (IN.)	TAIL BEARING TO POLISHED ROD (IN.)
2.	15.25	123.69	50.00	114.00	120.00

SLOW SPEED SHAFT TO TAIL BEARING VERTICAL DISTANCE = 114.00 IN. HORIZONTAL DISTANCE = 48.00 IN.

STROKE LENGTH = 74.38 IN. CRANK ANGLE SHIFT = 157.1 DEGREES

CRANK ANGLE (DEGREES)	POLISHED ROD POSITION (FRACTION OF STROKE)	POLISHED ROD POSITION (IN. FROM BOTTOM OF STROKE)	PERMISSIBLE LOAD (LBS.)
15	0.9803	72.925	-9726.
30	0.9220	68.585	-2589.
45	0.8307	61.792	-98.
60	0.7157	53.239	1261.
75	0.5679	43.734	2187.
90	0.4577	34.049	2772.
105	0.3338	24.830	3032.
120	0.2228	16.579	2860.
135	0.1301	9.684	1964.
150	0.0599	4.456	-556.
165	0.0155	1.157	-9149.
180	0.0000	0.000	********
195	0.0149	1.115	27890.
210	0.0606	4.510	18500.
225	0.1346	10.015	15273.
240	0.2327	17.311	13507.
255	0.3486	25.934	12311.
270	0.4750	35.338	11435.
285	0.6040	44.933	10833.
300	0.7273	54.105	10578.
315	0.8365	62.229	10906.
330	0.9233	68.684	12526.
345	0.9799	72.890	18890.
360	0.9999	74.385	1248792.

PEAK TORQUE	PISTON DIAMETER	CB CYL. PRESS. RANGE	STR. UNB. CYL. PRESS.
160000. IN.-LBS.	10.00 IN.	250 - 150 PSI.	63. PSI.

TAIL BEARING TO AIR CYL. BEARING 77.50 IN.

FIGURE 12

TYPE +2 UNIT TEST 2/23/71

PERMISSIBLE LOAD DIAGRAM FOR 160000.IN.-LB. UNIT TYPE 2.

STROKE= 74.38IN. CB CYL. PRESS. RANGE= 250 - 150 PSI.

CB CYL. PRESS. TO OFFSET ST. UNBAL.= 63. PSI. PISTON DIAMETER= 10.00 IN.

STROKE SCALE 1 IN.= 39.00IN. LOAD SCALE 1 IN.=12500.LBS.

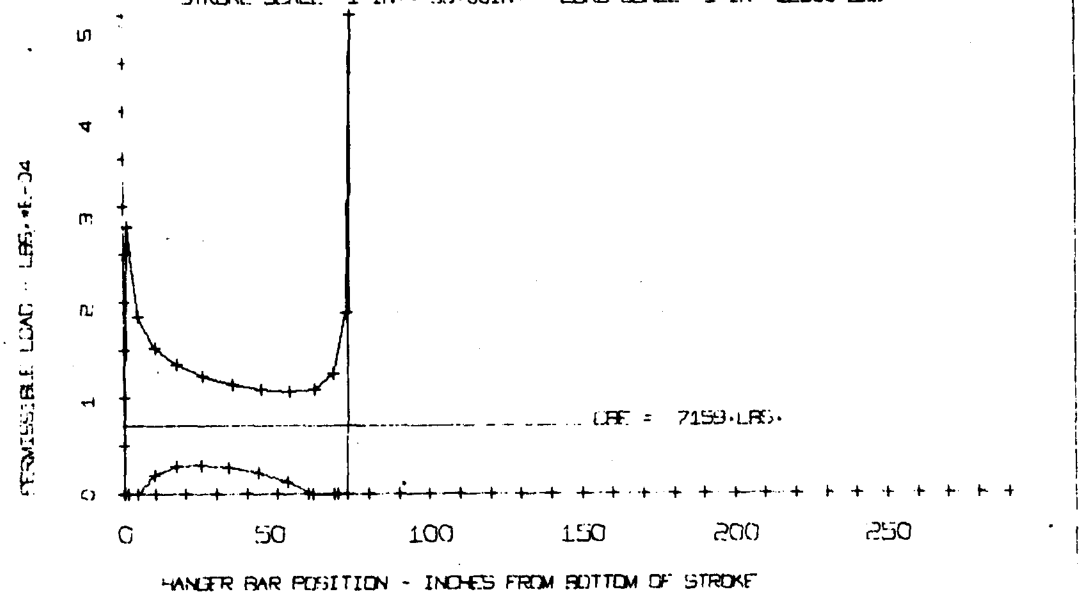

FIGURE 13

TYPE +3 UNIT TEST

PROGRAM NO. M6046 - TORQUE FACTOR CALCULATIONS
2/23/71

UNIT TYPE AND ROTATION	SLOW SPEED SHAFT TO CRANK BEARING (IN.)	SLOW SPEED SHAFT TO TAIL BEARING (IN.)	PITMAN BEARING TO TAIL BEARING (IN.)	CRANK BEARING TO PITMAN BEARING (IN.)	TAIL BEARING TO POLISHED ROD (IN.)
1.	53.75	244.69	256.00	182.38	312.00

SLOW SPEED SHAFT TO TAIL BEARING VERTICAL DISTANCE = 159.00 IN. HORIZONTAL DISTANCE = 186.00 IN.

STROKE LENGTH = 144.07 IN. CRANK ANGLE SHIFT = 130.5 DEGREES

CRANK ANGLE (DEGREES)	POLISHED ROD POSITION (FRACTION OF STROKE)	WELL LOAD TORQUE FACTOR	COUNTERBALANCE TORQUE FACTOR
15	0.0252	18.1518	0.2588
30	0.0683	29.2624	0.5000
45	0.1310	39.6221	0.7071
60	0.2117	48.9945	0.8660
75	0.3084	56.9096	0.9659
90	0.4173	62.7284	1.0000
105	0.5345	65.7002	0.9659
120	0.6539	65.0636	0.8660
135	0.7683	60.0941	0.7071
150	0.8693	50.1590	0.5000
165	0.9473	34.8180	0.2588
180	0.9925	14.0614	0.0000
195	0.9956	-11.2318	-0.2588
210	0.9504	-38.6608	-0.4999
225	0.8564	-63.9271	-0.7071
240	0.7226	-81.6551	-0.8660
255	0.5667	-87.8991	-0.9659
270	0.4102	-82.6401	-1.0000
285	0.2712	-69.4966	-0.9659
300	0.1597	-52.9672	-0.8660
315	0.0788	-36.2048	-0.7071
330	0.0274	-20.6323	-0.5000
345	0.0029	-6.5381	-0.2588
360	0.0028	6.2868	-0.0000

MARK II CRANK ANGLE OFFSET 24.0 DEGREES

FIGURE 14

TYPE +3 UNIT TEST

PROGRAM NO. M6046 - TORQUE FACTOR CALCULATIONS
2/23/71

UNIT TYPE AND ROTATION	SLOW SPEED SHAFT TO CRANK BEARING (IN.)	SLOW SPEED SHAFT TO TAIL BEARING (IN.)	PITMAN BEARING TO TAIL BEARING (IN.)	CRANK BEARING TO PITMAN BEARING (IN.)	TAIL BEARING TO POLISHED ROD (IN.)
1.	53.75	244.69	256.00	182.38	312.00

SLOW SPEED SHAFT TO TAIL BEARING VERTICAL DISTANCE = 159.00 IN. HORIZONTAL DISTANCE = 186.00 IN.

STROKE LENGTH = 144.07 IN. CRANK ANGLE SHIFT = 130.5 DEGREES

CRANK ANGLE (DEGREES)	POLISHED ROD POSITION (FRACTION OF STROKE)	POLISHED ROD POSITION (IN. FROM BOTTOM OF STROKE)	PERMISSIBLE LOAD (LBS.)
15	0.0252	3.632	27744.
30	0.0683	9.853	23851.
45	0.1310	18.888	21744.
60	0.2117	30.513	20030.
75	0.3084	44.436	18428.
90	0.4173	60.131	16883.
105	0.5345	77.012	15425.
120	0.6539	94.216	14095.
135	0.7683	110.701	12973.
150	0.8693	125.248	12240.
165	0.9473	136.491	12549.
180	0.9925	143.003	10757
195	0.9956	143.453	-9677.
210	0.9504	136.929	526.
225	0.8564	123.396	1944.
240	0.7226	104.119	2580.
255	0.5667	81.652	3238.
270	0.4102	59.110	4107.
285	0.2712	39.075	5155.
300	0.1597	23.013	6145.
315	0.0788	11.356	6496.
330	0.0274	3.949	4481.
345	0.0029	0.423	-13783.
360	0.0028	0.413	46899.

PEAK TORQUE 320000. IN.-LBS. MAX. CB MOMENT 990000. IN.-LBS. STRUCTURAL UNBALANCE -4000. LBS.

MARK II CRANK ANGLE OFFSET 24.0 DEGREES

FIGURE 15

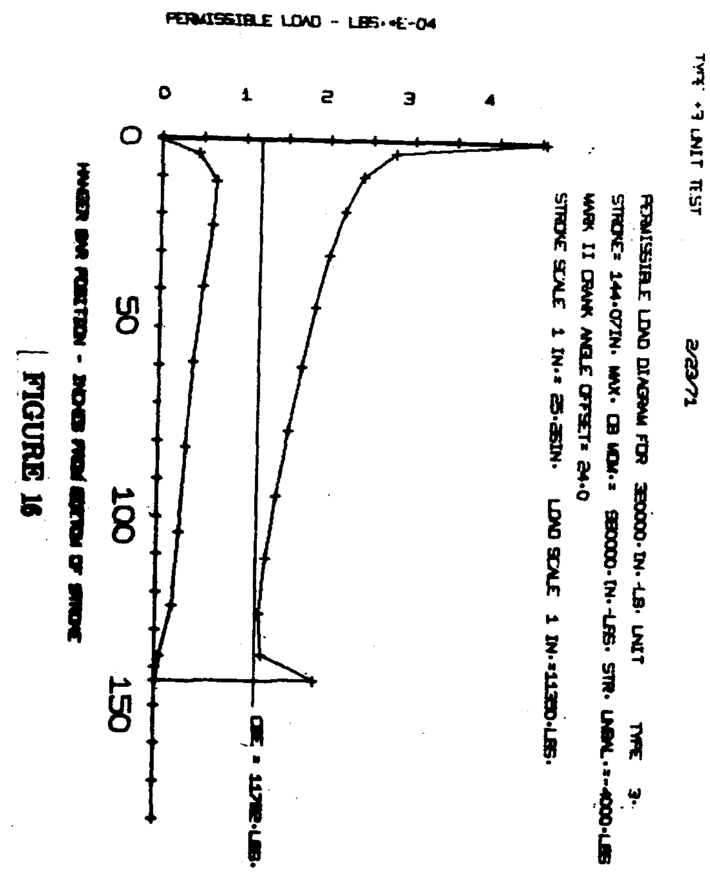

FIGURE 16

loads consists of torque rating of the gear box and counterbalance data. If in addition a permissible load diagram is wanted, the stroke scale and weight scale must be input.

Once a permissible load diagram is drawn for a unit, the plot is applicable until the stroke length or the counterbalance effect is altered; providing, of course, the scale of the dynamometer cards is not changed. A change in pump size, rods, setting depth, fluid level, SPM or tubing size will not affect the validity of the plot. Adding counterbalance moves the plot up the "y" (load) axis an amount corresponding to the added counterbalance effect. Reducing counterbalance moves the plot down the "y" axis an amount equal to the reduced counterbalance effect.

Some suggested program applications follow. If the required input is known, the plot can be drawn prior to going to a well under study and an instant evaluation of the gear box load can be made at the well site by overlaying the plot with a dynamometer card taken at the well. If a dynamometer card is available, a well can be counterbalanced at the office. This can be accomplished by running several plots each with a different counterbalance effect and selecting the counterbalance effect of the plot that best suits the dynamometer card.

SUMMATION

Field experience, although very limited, indicates that high speed operation can be satisfactory. It has been established that controlled overloading of units with proper surveillance and maintenance can result in satisfactory operations. It has been demonstrated that units can be more efficiently loaded with the fast, short-stroke pumping method. The use of these methods, where applicable, in conjunction with other aids such as extra high slip motors and sinker bars, should result in better and fuller utilization of existing equipment, and thereby save money through delayed investments for larger units and in some cases make the purchase of the larger equipment unnecessary. Reduced expenses can also result.

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