COMPARING CLASS I AND CLASS III
VARYING PUMPING UNIT GEOMETRIES

Jerry Watson, Grooves, Inc.

ABSTRACT

This paper presents the advantages and disadvantages of the class I and class III lever system varying geometry pumping units.

By significantly modifying the lengths of the 5-bar linkage system that controls the geometric motion of the polish rod, varying geometries have been achieved in class I units. Varying geometry is achieved when the upstroke of the pumping unit is accomplished in greater than 180 degrees of crank-arm rotation and the downstroke in less than 180 degrees. Previously varying geometries were generally limited to the class III lever system design pumping units. This paper will discuss and compare class I and class III lever system varying geometries.

INTRODUCTION

The motion of the polish rod in a sucker rod pumping system is most important. The old belief of just "up and down is ok" is being seriously questioned. With the rapid increase in operating and maintenance cost and the heavy push to reduce well downtime, some pumping unit manufacturers are taking a hard look at more fully utilizing the up and down polish rod motion in an effort to reduce customer costs.

With the aid of computers, it is now possible to study in detail the up and down motion of the polish rod. It is also possible to determine where changes in polish rod velocity and acceleration could be made to improve productivity and efficiency of the unit while not increasing rod loading. As a result, a pump unit with a different geometry has emerged - the varying geometry class I lever system unit.

The varying geometry of a unit causes the upstroke to be accomplished in more than 180 degrees (typically 188 to 198 degrees) of crank-arm rotation and the downstroke in less than 180 degrees (typically 172 to 162 degrees). This does not seem like much of a change from the old conventional geometry, but very significant gains can be realized. A decreased peak torque requirement, increased operating efficiency, increased production and in a majority of applications, a decrease in rod stress are some of these gains.

THEORY

The varying geometry is not a new idea; in fact, the class III lever system (Fig. 1, type I) varying geometry has been around for many years and has proven its value. The class I lever system unit with varying geometry is new (Figure 1, type II and III).

All three types of units achieve varying geometry by moving the crankshaft such that it is not directly under the tail bearing (or cross yoke bearing in the case of the type I unit). Each unit also shifts the counterweight into a leading or lagging position to achieve maximum effect.

The type I unit's cross yoke bearing (similar to tail bearing) moves approximately the same distance above and below the sampson shaft. This is also true of the tail bearing on the type II unit.

The type III unit's crank arm and pitman arm are longer. This permits the tail bearing to rotate in an arc that extends (relative to the sampson shaft) from almost horizontal at the top of the stroke to almost vertical at the bottom of the stroke.

In order that an objective comparison be made of each unit geometry and their type of polish rod motion generated, a modified version of H. E. Gray's computer program, "Kinematics of Oil Well Pumping" was used. The modification consisted of incrementing the program output by polish rod position rather than crank-arm rotation. In this way all geometries could easily be studied and compared, regardless of the type of geometry.

DISCUSSION ACCELERATION AND VELOCITY PLOT OUTPUT

Fig. 2 is a typical plot of the polish rod motion generated by a type III (see fig. 1) unit geometry. Let us discuss the plot itself rather than the specific data at this time. 1) The column just to the right and left of the plot area "ck/ang" is the crank angle. This is the number of degrees the crank-arm has rotated starting at the bottom of the upstroke. 2) The bottom of the stroke starts at the top of the plot area. 3) The upstroke is the top 1/2 of the plot area. 4) The downstroke is the bottom 1/2 of the plot area. 5) The left column under the heading "polish rod" is plotted data. The right and most important column is the polish rod position given in 2.5% increments. 6) The vertical line in the middle of the plot area is the zero line. All values are measured from this line horizontally. Positive or negative values of data simply mean a change of data sense or direction. 7) All data plotted is non-dimensional.

ANALYZING AND COMPARING PLOTS

Fig. 3 is a plot comparing a type I unit (represented by dotted lines) with a type III unit (represented by solid lines).

You will note that during the first 5 to 7.5% of the upstroke the acceleration of the type III unit is higher than the type I. At first glance this would appear to be detrimental, but not so. Consider that this is the portion of the upstroke when the rods are stretching as the unit is picking up well weight. Only in wells where the maximum load takes place at the beginning of the upstroke could this be detrimental. Generally the maximum load occurs at a polish rod position from 30 to 60% above the bottom of the stroke. This higher acceleration at the very beginning of the upstroke tends to open up the left end of the dynamometer card which is otherwise closed (observe dynamometer cards on fig. 6).

Notes where the area of peak loads would occur. The velocity and acceleration are comparable if not lower on the type III than the type I. This lower acceleration and velocity frequently lowers maximum rod load and correspondingly rod stress.

Toward the end of the upstroke the type III unit's acceleration increases slightly over the acceleration of the type I unit. This tends to open up the right end of the dynamometer card. The dynamometer card in fig. 6 demonstrates the opening up of the card. A card that is opened up on both ends indicates that the work being done during the stroke is distributed over a greater portion of the stroke.

Gravity must overcome the inertia of the rods to begin the downstroke. At this point in the downstroke it is desirable to have a slow but steadily increasing velocity with an acceleration as constant as possible. This action generally contributes to higher minimum well loads. This is particularly beneficial to fiberglass rods. The type III unit achieves this desired characteristic.

It should be pointed out here that most well pounding conditions occur at the upper portion of the downstroke. High accelerations and velocities at this point tend to aggravate a pounding condition by increasing the impact velocity, thusly increasing impact loads.

The type III unit has a relatively low and constant acceleration at the beginning of the downstroke. The polish rod velocity steadily increases until a point approximately 32% from the bottom of the downstroke. The peak downward velocity of the type I and III units are approximately equal but occur at different points in the downstroke.

Starting at a point approximately 20% from the bottom of the downstroke, the polish rod acceleration of the type III unit exceeds that of type I. This higher acceleration and rapid deceleration, at the bottom of the stroke, is at a point in the downstroke past the point where minimum rod loading occurs. As a result, the minimum load is not driven lower. This higher acceleration and rapid deceleration at the bottom of the stroke tends to encourage a longer downhole pump stroke. This would result in yielding higher production per stroke. This also contributes to opening up the left end on the dynamometer card. This action takes advantage of the elasticity of fiberglass and similar rods to increase the downhole pump stroke length. A word of caution must be inserted: If a pounding condition exists where the plunger impacts the fluid at a point less than 20% from the bottom of the stroke, the type III unit will greatly aggravate the pounding condition.

Fig. 4 shows the acceleration and velocity of a type II geometry (dotted lines) in comparison with the type III geometry (solid lines). Many of the advantages, pointed out in the previous discussion, of the type I and type III units are the same for the comparison between the type II and type III units. One exception should be noted: At the beginning of the down stroke, the type II has a very high acceleration and velocity. This would aggravate a pounding condition to a greater extent than would the type I.

While it is not within the scope of this paper, the author feels it would be of interest to the reader to present an acceleration and velocity comparison of a type III and a conventional unit geometry (see Fig. 5).

TORQUE FACTOR COMPARISON

A comparison of the maximum upstroke and downstroke torque factors can be seen in Fig. 8.

Upstroke torque factors are by far more important than the downstroke torque factors. The type III has a slightly lower maximum torque factor on the upstroke than other units with a varying geometry. The lower the torque factor on the upstroke the greater the mechanical advantage of the 5-bar linkage system. Low torque factors on the upstroke mean that the prime mover must produce less torque, and thereby consume less power. The peak torque may be lower to accomplish the same pumping job, and a smaller amount of counterbalance weight may be required to "balance" the unit. The reduction in counterbalance weight means less power is required to lift that same weight on the downstroke. Due to lower torque factors on the upstroke, there is a significant increase in efficiency and a reduction in operating costs.

Higher torque factors on the downstroke are not detrimental because the weight of the fluid has been transferred to the tubing and the polish rod load is much lower. Lower downstroke torque factors do contribute a small amount to increased operating efficiency and lower downstroke torque.

EFFICIENCY

It may be deduced from the discussion on torque factors that varying geometry units are more efficient to operate than conventional units.

The type II and III units may have a slight advantage over the type I unit because of the overall slightly lower torque factors and the fact that a class I unit (types II and III) usually has a positive structural unbalance. The positive structural unbalance subtracts from the well weight, in effect lowering the well load. This reduces the power required to lift the well load. The class III (type I), on the other hand, has a negative structural unbalance that effectively adds to the well weight, and thusly increases the power required to lift the well load. This also adds to the amount of counterweight that is required to counterbalance the well.

A computer analysis using the NABLA Corporation's SRODE$ program shows that the type III unit should reduce energy cost from 18 to 26% compared to identical conditions using a conventional unit.

REDUCED CAPITAL INVESTMENT

Compared with conventional units varying geometry units will generally require lower torque ratings, less counterbalance weight (true for only type II and III), and generally can use smaller prime movers , all of which will reduce initial capital investment.

REDUCED MAINTENANCE COST

The slower upstroke of varying geometry units frequently lower the maximum loads which results in reduced rod stress. This should result in reduced rod failures and maintenance costs. A word of caution: with a slower upstroke comes a faster downstroke. If the geometry does not handle the rods correctly, minimum loads may be lowered to a point where the rods are actually loaded more (Goodman Diagram) even though the maximum load is lowered. This is illustrated in the summary of computer comparisons (Fig. 7). In this case a maximum pumping speed will have to be imposed.

DISADVANTAGES OF VARYING GEOMETRIES

All units are sensitive to the direction of rotation and must be rotated in the specified direction. Well pounding conditions may be aggravated (compared to what would occur with a conventional unit) depending on where the position of the pounding condition occurs in the downstroke and the geometry of the unit in use.

CONCLUSION

It must be pointed out that there is no ideal pumping unit or geometry for all well conditions and rod designs. It does appear that in most cases the varying geometry units offer definite advantages over conventional units. The type III unit's varying geometry would seem to offer better polish rod acceleration and velocity characteristics over the type I and II units, using the well conditions as indicated by the computer comparison (results presented in Fig. 7). This can translate into increased operating efficiency (18 to 24%), increased production per stroke, decreased peak torque per barrel lifted, reduced capital investment, and in some cases decreased rod loading, all factors that will help producers reduce the overall cost of getting oil out of the ground.

DEFINITIONS

1) Class I lever system - The type of lever system that is found on conventional units. With the well to the right, the crankshaft is to the left of the sampson shaft and the sampson shaft is to the left of the well. See Fig. 1. Type II and III units are class I.

2) Class III lever system - The type of lever system that is found on push-up type pumping units. With the well to the right, the sampson shaft is to the left of the crankshaft and the crankshaft is to the left of the well. See Fig. 1. Type I unit is a class III.

3) Structural unbalance - Equal to the force at the polish rod required to hold the beam in a horizontal position with the pitmans disconnected from the crank pins. This force is positive when acting downward and negative when acting upward.

BIBLIOGRAPHY AND/OR REFERENCES

1. H. E. Gray, "Kinematics of oil-well pumping units". Paper presented before Mid-Continent District, API Division of Production, March, 1963.

2. NABLA Corporation, Midland, Texas. The "SROD" and "SRODE" computer program.

ACKNOWLEDGMENTS

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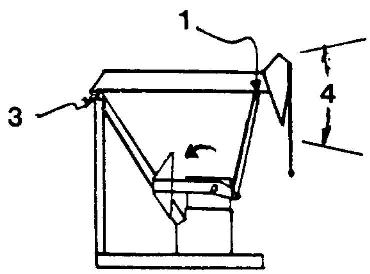

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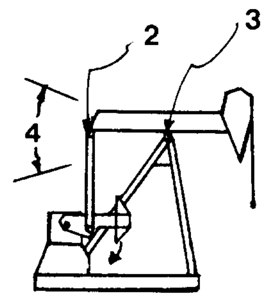

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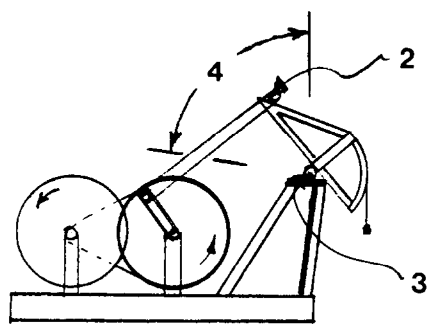

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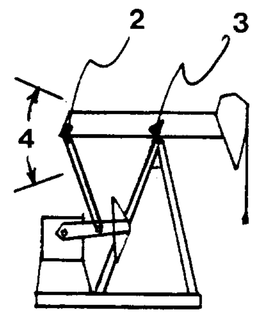

CONVENTIONAL

1. CROSS YOKE BEARING
2. TAIL BEARIG
3. SAMPSON SHAFT
4. TAIL BEARING (CROSS YOKE BEARING) MOVEMENT.

FIGURE 1
PUMPING UNIT TYPES

GROOVES, INCORPORATED - KINEMATICS OF OIL WELL PUMPING UNITS

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UNIT MANF.- GROOVES API UNIT SIZE.-228/213/86 ...... TYPE III (class III)

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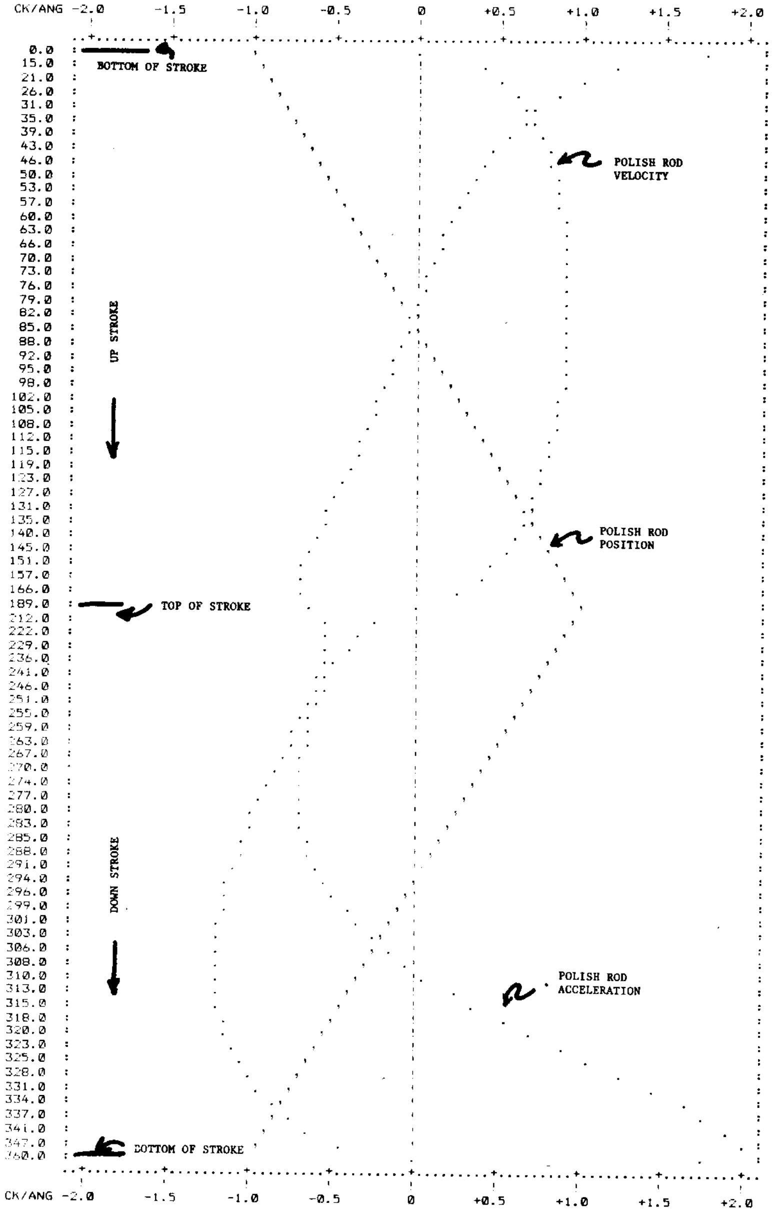

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31.0	-0.80	10.0 %
35.0	-0.75	12.5 %
39.0	-0.70	15.0 %
43.0	-0.65	17.5 %
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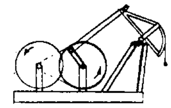
360.0	-1.00	0.0 %
CK/ANG	POLISH ROD	

P O L I S H R O D

(NON-DIMENSIONAL)

, = POSITION . = VELOCITY . =ACCELERATION



TYPE III

FIGURE 2
POLISH ROD ACCELERATION AND VELOCITY CURVES TYPE III UNIT

GROOVES, INCORPORATED - KINEMATICS OF OIL WELL PUMPING UNITS

UNIT MANF.- LIFKIN API UNIT SIZE.-M 228/213/86

.... TYPE I (class III)
_______ TYPE III (class I)

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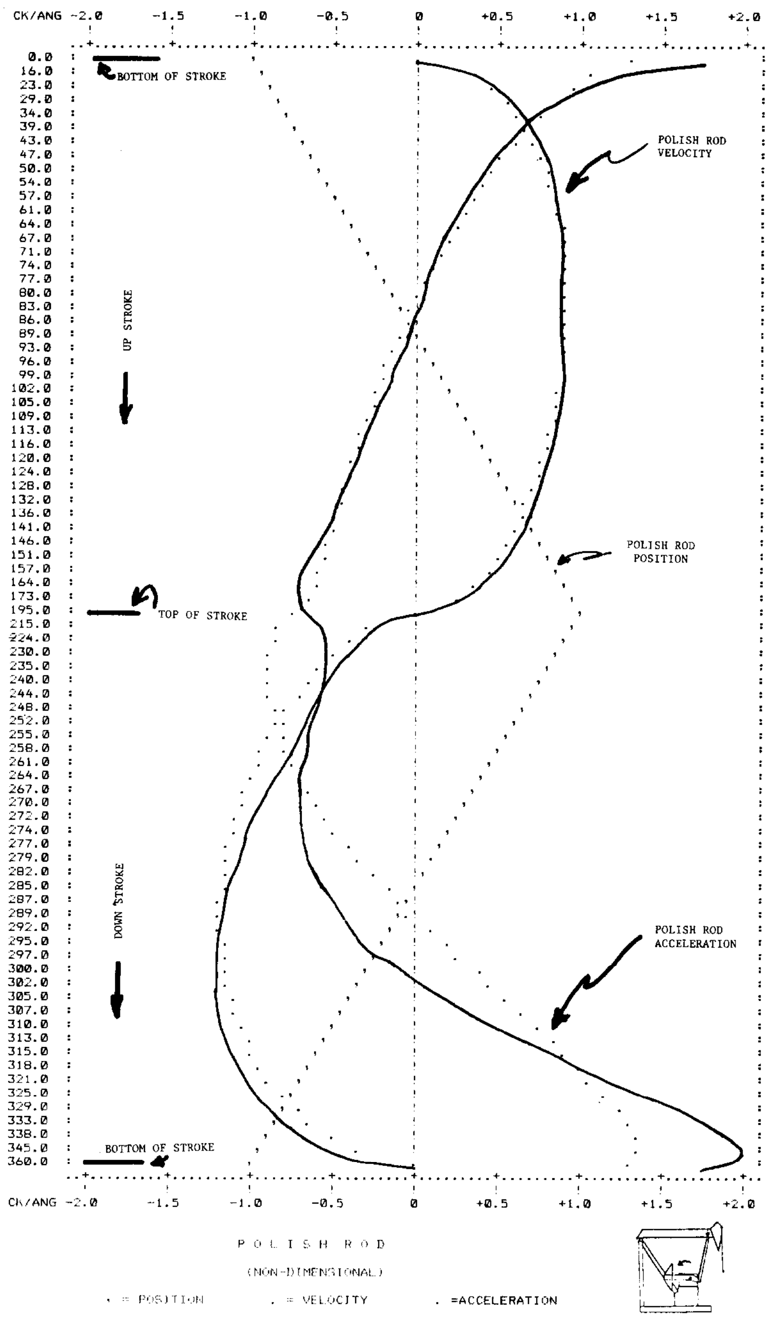

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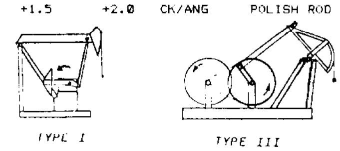

FIGURE 3
POLISH ROD ACCELERATION AND VELOCITY CURVES TYPE 1 AND TYPE III

GROOVES, INCORPORATED - KINEMATICS OF OIL WELL PUMPING UNITS

UNIT MANF.- CMI   API UNIT SIZE.-228/213/86   ...... TYPE II (class I)   ______ TYPE III (class I)

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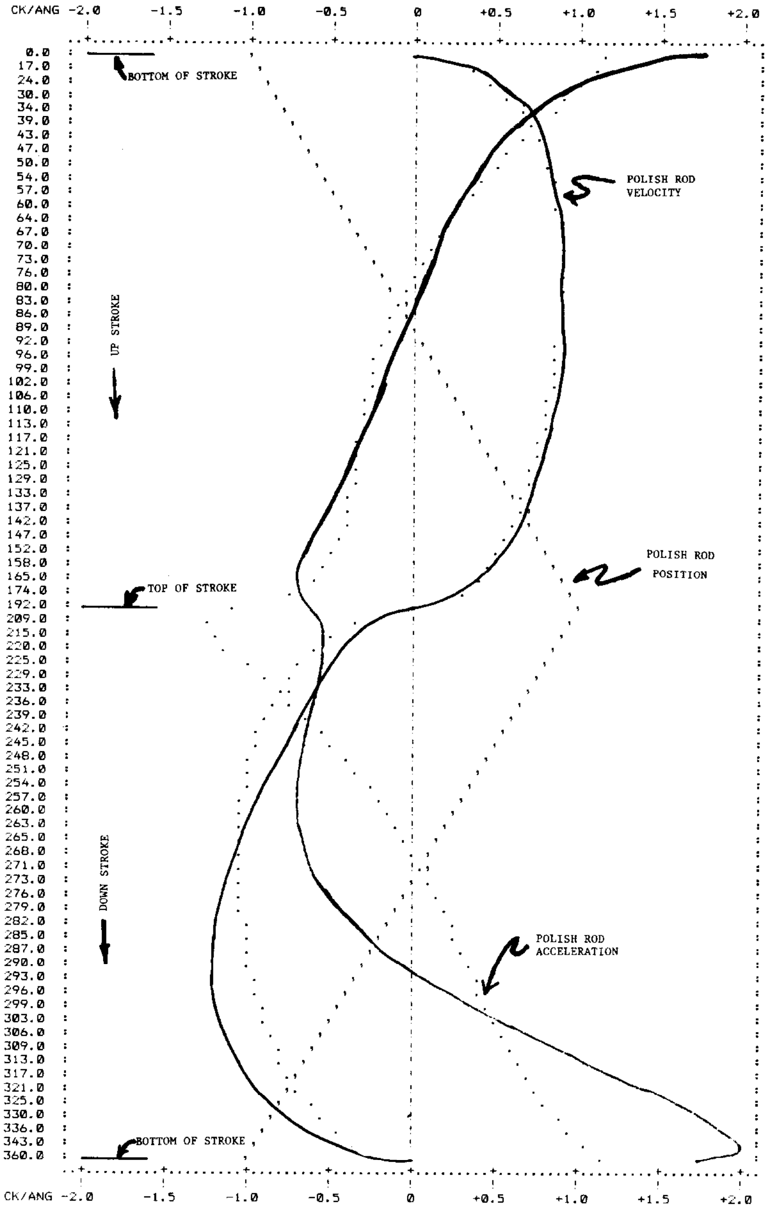

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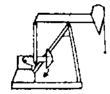
360.0	-1.00	0.0 %

CK/ANG   POLISH ROD


TYPE II

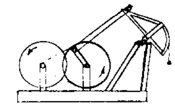

TYPE III

FIGURE 4
ACCELERATION AND VELOCITY CURVES TYPE II AND TYPE III

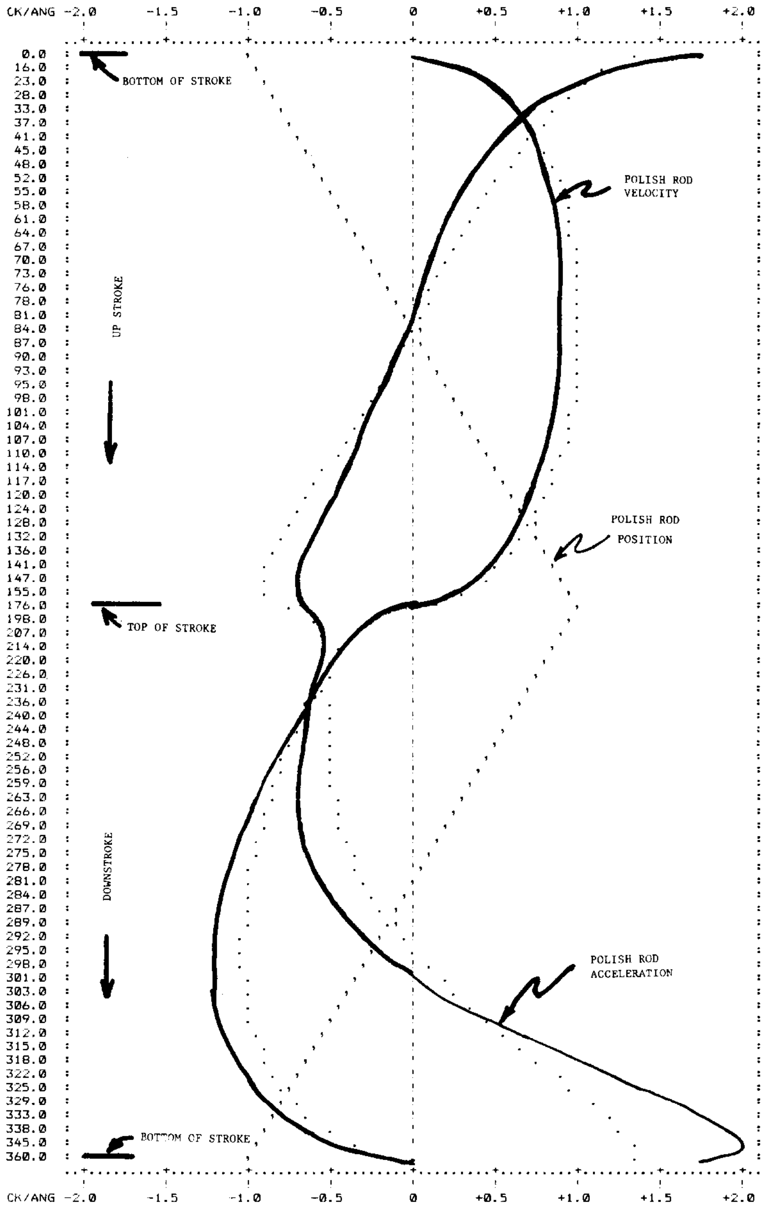
GROOVES, INCORPORATED - KINEMATICS OF OIL WELL PUMPING UNITS

UNIT MANF.- LUFKIN   API UNIT SIZE.-C 228/213/86

..... CONV. (class III)
____ TYPE III (class III)

NOTICE: THIS PROGRAM DOES NOT TAKE INTO ACCOUNT THE AFFECTS OF INERTIA.

THIS PROGRAM IS A MODIFIED VERSION OF H. E. GRAYS (SHELL DEVELOPEMENT CO. HOUSTON) 'KINEMATICS OF OIL WELL PUNPING UNITS' PROG.

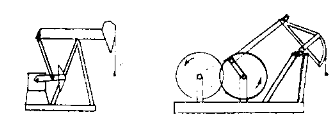


CK/ANG	POLISH ROD	
0.0	-1.00	0.0 %
16.0	-0.95	2.5 %
23.0	-0.90	5.0 %
28.0	-0.85	7.5 %
33.0	-0.80	10.0 %
37.0	-0.75	12.5 %
41.0	-0.70	15.0 %
45.0	-0.64	17.5 %
48.0	-0.60	20.0 %
52.0	-0.54	22.5 %
55.0	-0.49	25.0 %
58.0	-0.45	27.5 %
61.0	-0.40	30.0 %
64.0	-0.35	32.5 %
67.0	-0.30	35.0 %
70.0	-0.24	37.5 %
73.0	-0.19	40.0 %
76.0	-0.14	42.5 %
78.0	-0.10	45.0 %
81.0	-0.05	47.5 %
84.0	0.00	50.0 %
87.0	0.06	52.5 %
90.0	0.11	55.0 %
93.0	0.16	57.5 %
95.0	0.20	60.0 %
98.0	0.25	62.5 %
101.0	0.30	65.0 %
104.0	0.35	67.5 %
107.0	0.40	70.0 %
110.0	0.45	72.5 %
114.0	0.51	75.0 %
117.0	0.55	77.5 %
120.0	0.60	80.0 %
124.0	0.65	82.5 %
128.0	0.70	85.0 %
132.0	0.75	87.5 %
136.0	0.80	90.0 %
141.0	0.85	92.5 %
147.0	0.90	95.0 %
155.0	0.95	97.5 %
176.0	1.00	100.0 %
198.0	0.95	97.5 %
207.0	0.90	95.0 %
214.0	0.85	92.5 %
220.0	0.80	90.0 %
226.0	0.75	87.5 %
231.0	0.70	85.0 %
236.0	0.65	82.5 %
240.0	0.60	80.0 %
244.0	0.55	77.5 %
248.0	0.50	75.0 %
252.0	0.45	72.5 %
256.0	0.39	70.0 %
259.0	0.35	67.5 %
263.0	0.29	65.0 %
266.0	0.24	62.5 %
269.0	0.20	60.0 %
272.0	0.15	57.5 %
275.0	0.10	55.0 %
278.0	0.05	52.5 %
281.0	-0.00	50.0 %
284.0	-0.06	47.5 %
287.0	-0.11	45.0 %
289.0	-0.15	42.5 %
292.0	-0.20	40.0 %
295.0	-0.25	37.5 %
298.0	-0.31	35.0 %
301.0	-0.36	32.5 %
303.0	-0.40	30.0 %
306.0	-0.45	27.5 %
309.0	-0.50	25.0 %
312.0	-0.55	22.5 %
315.0	-0.60	20.0 %
318.0	-0.65	17.5 %
322.0	-0.71	15.0 %
325.0	-0.75	12.5 %
329.0	-0.80	10.0 %
333.0	-0.85	7.5 %
338.0	-0.90	5.0 %
345.0	-0.95	2.5 %
360.0	-1.00	0.0 %
CK/ANG	POLISH ROD	

P O L I S H R O D

(NON-DIMENSIONAL)

, = POSITION . = VELOCITY . =ACCELERATION



CONVENTIONAL TYPE III

FIGURE 5
ACCELERATION AND VELOCITY CURVES CONVENTIONAL AND TYPE III

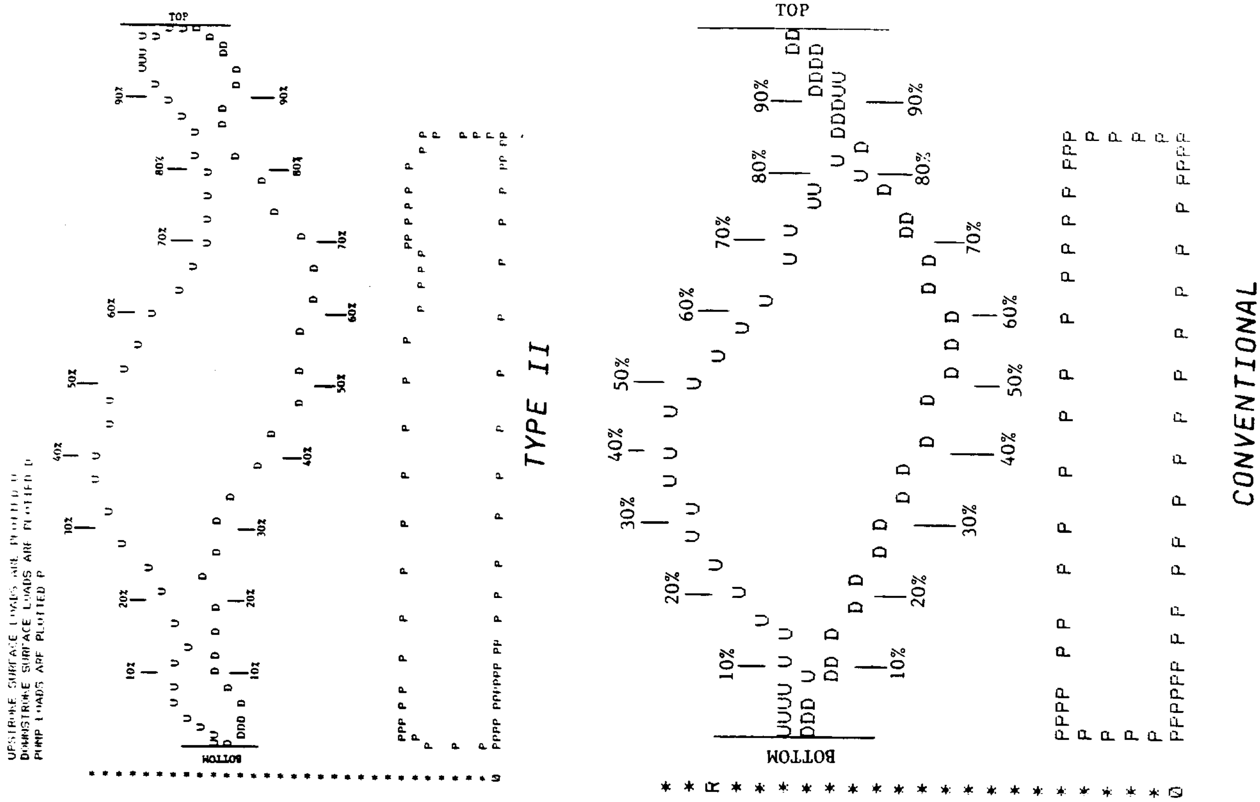
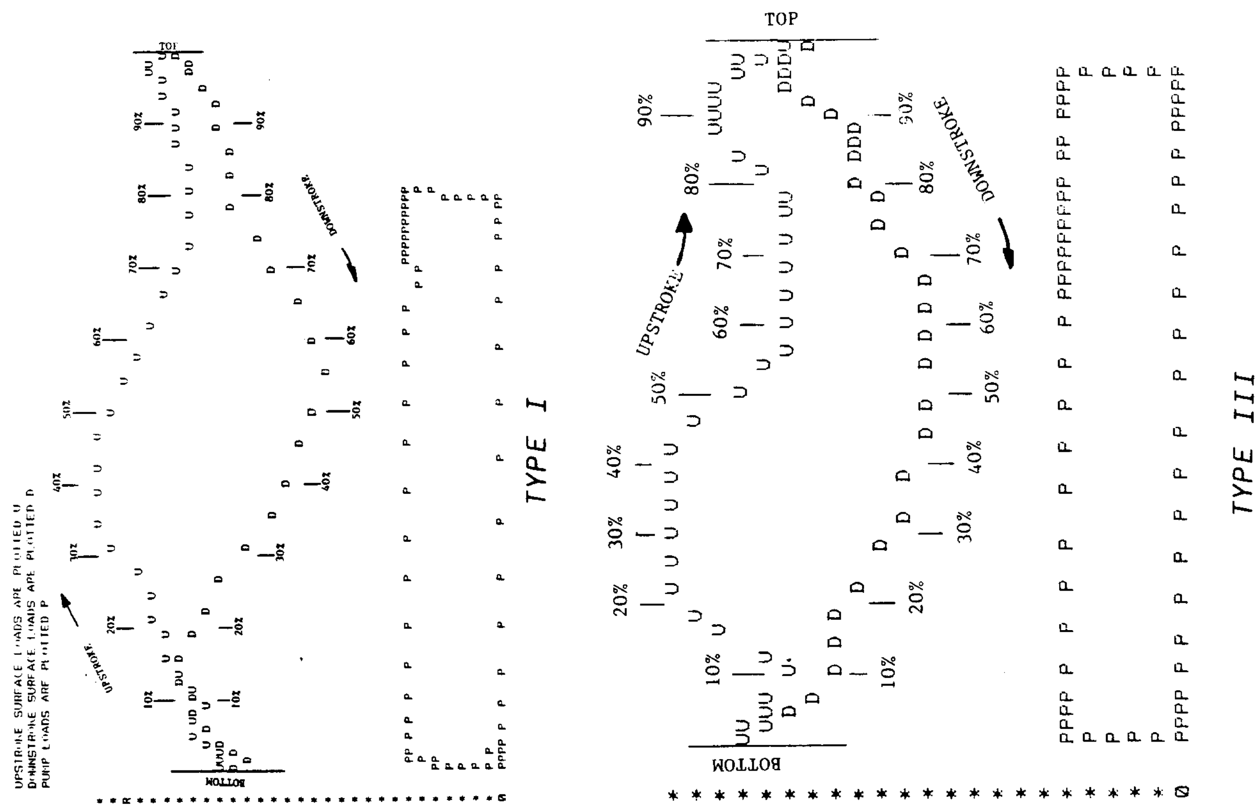


FIGURE 6
DYNAMOMETER CARDS INCREMENTED BY POLISH ROD POSITION



	TYPE I	TYPE II	TYPE III	CONV.
NET.PROD.*	98.4	104.9	118.5	104.2
SPM **	10.5	10.5	10.6	10.7
STROKE:#				
SURFACE	64.1	64.0	64.1	65.0
PUMP	51.2	54.7	61.3	53.6
PEAK TORQUE ##	83.5	111.9	132.3	148.9
% ROD LOADING!	86.1	85.1	81.3	86.2
ROD STRESS!!				
MAXIMUM	25314	25656	25318	26082
MINIMUM	11271	12056	12472	12462

* NET PRODUCTION : STATED IN BARRELS PER DAY
** SPM: STROKES PER MINUTE
\# STROKE IN INCHES: SURFACE AND DOWNHOLE NET STROKE.
\#\# PEAK TORQUE: GIVEN IN THOUSANDS OF INCH POUNDS.
! ROD LOADING AS A % OF API GOODMAN GUIDE CLASS K RODS.
!! ROD STRESS GIVEN IN POUNDS PER SQUARE INCH.

THE ABOVE DATA WAS DEVELOPED ON A 6000 FT WELL, EQUIPPED WITH AN API 76 ROD STRING, 1.25 INCH PUMP. PRIME MOVERS WERE IDENTICAL IN ALL CASES. THE WELL DATA WAS SUPPLIED FOR THE AUTHOR BY ARCO. THE NABLA CORP. SROD COMPUTER PROGRAM WAS USED.
THE ABOVE DATA IS CERTAINLY NOT CONCLUSIVE AND WILL NOT APPLY TO ALL WELLS BUT WILL SERVE TO ESTABLISH TRENDS AS CONTROLLED BY THE UNIT GEOMETRY.

FIGURE 7
SUMMARY OF COMPUTER COMPARISONS

	TYPE I	TYPE II	TYPE III	CONV.
MAXIMUM UPSTROKE TORQUE FACTOR	39.70	39.24	38.94	44.82
MAXIMUM DOWNSTROKE TORQUE FACTOR	52.81	45.04	52.08	45.09

NOTE: THE ABOVE TORQUE FACTORS ARE GIVEN FOR A 228 UNIT WITH 86 INCH STROKE.

FIGURE 8
TORQUE FACTOR COMPARISONS