PERMISSIBLE LOAD ENVELOPES FOR BEAM PUMPING UNITS

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ABSTRACT

The landmark paper on beam pumping unit permissible load diagrams was presented in 1960 by Mr. Robert H. Gault (1). A permissible load diagram is simply a plot of the positive gearbox torque rating (converted to pounds of polished rod load), versus polished rod position. This plot is valid for any given counterbalance effect (CBE) and pumping unit. It enables such things as quickly telling whether a given unit is overloaded, comparing different unit geometries, or comparing effects of different CBE levels.

Higher water cuts and deeper wells are more common in today's world. To maximize production rates, operations are moving toward longer stroke lengths, larger pump plungers, and higher CBE levels. Negative gearbox torque becomes a factor at higher CBE, and has not been presented in previous literature on permissible loads.

This paper presents the <u>permissible envelope</u>, which accounts for both positive <u>and</u> negative gearbox torque rating. Permissible envelopes enable more complete definition of acceptable pumping unit rod loads than has been available in the past.

INTRODUCTION

Decades of secondary and tertiary recovery operations have led to a common problem in many reservoirs. Net oil production is declining, while total fluid inflow into well bores is steadily increasing. Producers today frequently have many high volume, low income wells that are more expensive to operate, and less productive, than they were in the initial, high oil production stage.

One practice gaining popularity in this environment is analyzing performance and efficiency of production systems, and trying to optimize the operating parameters for maximum efficiency.

Dynamometer card analysis of a producing well, which produces a net torque analysis of the pumping unit, has historically been fairly straightforward. In recent years, operating trends have been toward fluid inflow increases, longer stroke lengths, larger pump plungers, and/or larger sucker rods.

With the trend toward deeper and deeper wells, it is understandable why CBE on new units has been steadily increasing over the years. At these elevated CBE levels, there has been a an unusual phenomenon.

There have been pumping units that had exceptionally high negative torques on the dynamometer card analysis. In some cases, that negative torque has been high enough to overload the gearbox beyond its rated torque capacity, even though the unit was not too far away from ideal counterbalance.

There have been various explanations offered, including "Ignore it - it's not valid". To understand negative gearbox torque requires us to understand that the geometry of a pumping unit, and the CBE level, affect the capability of that pumping unit to handle a particular production condition.

A dynamometer card, which is a graphic picture of polished rod load versus polished rod position resulting from that production condition, is a good starting point for an understanding of negative torque. Typically, an analysis of gearbox torque for a particular well is obtained from the dynamometer card for that well. However, the classic torque analysis will only show "what"; it will not show "why".

PERMISSIBLE LOADS

The primary work giving us an understanding of the relationship between pumping unit geometry, gearbox torque, and well loads was done by Mr. Robert H. Gault in 1960, in his paper "Permissible Load Diagrams for Pumping Units" (1).

Torque calculations for later pumping unit geometries are shown in API SPEC 11E, Specification for Pumping Units (2). Using a development comparable to Gault, updated for the later API equations, the starting point is the relation:

$$Tn = [TF * (W - B)] - [M * \text{Sine}(\text{Theta} - \text{Tau})]$$

Where:

Tn = net torque on gearbox, inch-pounds

TF = torque factor at crank pin angle Theta

W = polished rod load, at crank pin angle Theta, pounds

B = structural unbalance, pounds

M = maximum rotary counterbalance moment, inch-pounds

Theta = crank pin angle; is zero at 12-o'clock and increases in clockwise direction for Class I; for Class III units is zero at 6-o'clock and increases in counterclockwise direction. (Viewed with wellhead to the right)

Tau = counterweight phase angle

The equation above is normally used to find the net gearbox torque (at any crank pin angle of interest) resulting from the polished rod load at that angle. These torque values are plotted on a graph against the polished rod position, resulting in a net torque curve. Torque loading is then evaluated for the gearbox, to verify operation within torque rating.

Calculations may also be used to enable adjusting to a CBE which will balance the peak torque during the upstroke with the peak torque during the downstroke. By changing CBE to this value, the lowest possible torque on the pumping unit gearbox for that specific pumping condition will be obtained. This is the primary use most operators currently apply the net torque calculations to.

The equation was rearranged by Gault, to solve for what he termed the "permissible load"; as a function of rated gearbox torque capacity, as follows:

W = ({Tn + [M * Sine(Theta - Tau)]} / TF) + B

This equation was solved at a series of crank pin angles, Theta, using the rated gearbox torque for Tn, and the counterbalance effect at 90 degrees desired for evaluation. The resulting set of allowable polished rod loads, W, was then plotted as a function of polished rod position. This graph was termed the "Permissible Load Diagram".

Basically, for a given pumping unit and CBE, this graph expresses the gearbox capacity in a different manner. Normally we define gearbox capacity in terms of inch-pounds of torque at the low speed shaft. The equation above permits us to express the capacity in terms of pounds of polished rod load lifting capacity.

The Permissible Load Diagram, then, is a graph of the upstroke maximum and downstroke minimum polished rod load LIMITS beyond which the polished rod load cannot go without overloading the gearbox above its rated torque. These limits were originally intended to define the limits within which any polished rod load was acceptable.

PERMISSIBLE LOAD LIMITATIONS

In 1982, I observed that the derivation should be extended to include a second case, for the negative gearbox torque direction. The original derivation assumed that gearbox torque is positive only.

Positive Torque

Pumping unit gearboxes are rated by manufacturers for a peak torque which is independent of direction. If the gearbox and prime mover are PROVIDING power to lift or lower the sucker rods and counterweights, then the gearbox is providing POSITIVE torque.

Negative Torque

If the gearbox and prime mover are RECEIVING power from the sucker rods and counterweights, then the gearbox is subjected to NEGATIVE torque. Regardless of torque direction, the gearbox torque rating of the manufacturer should not be exceeded; or a shorter than desired gearbox life may result.

As further confirmation of this effect, pumping units which are designed for bi-directional rotation have torque ratings which are the same for either direction of gearbox rotation, and therefore either direction of torque loading.

Most people have heard prime movers operating with a relatively constant load, such as compressors, water pumps, and others. In these instances, the prime movers' RPM cannot be heard to change. A tachometer on the prime movers' output shaft provides further verification of the constant RPM.

Prime movers on most pumping units are not what would be termed "constant RPM". Rather, they change RPM continuously throughout each revolution of the pumping unit. As the torque loads change, most units will be observed to slow down; then to speed up, possibly to speed up dramatically as the load changes, then to slow down as load continues changing.

Overspeed

As RPM increases, the prime mover acts as a brake while it is forced into an overspeed condition. This is the condition which creates the prime mover noise indicative of high RPM, as the pumping unit is physically forced into an overspeed condition.

In some cases, the RPM change of the unit is large enough that it may be not only heard but also visually observed. First the unit will slow down as positive torque increases, then speed up as torque decreases to zero. Then the unit will speed up beyond the no-load RPM of the prime mover, as negative torque is applied to the gearbox from the sucker rods and counterweights.

In the overspeed condition, the gearbox must transmit the torque required to force the prime mover to a much higher RPM than it would run at if the V-belts were removed and the prime mover operated without any load at all.

This condition, on an electric motor driven unit, results in the pumping unit motor turning into a generator. The negative torque on the gearbox provides the power required to keep the "generator" turning faster than no-load RPM. Similar negative torques occur with gas engine drives. Negative torques may easily be in excess of the rated gearbox torque capacity, just as positive torques may.

An overspeed condition may occur during the upstroke and/or during the downstroke on some pumping units and wells. It can occur on properly counterbalanced units operating with dynamometer card shapes which, for that specific pumping unit and CBE level, produce wide variations in gearbox torque.

Even more exaggerated changes in RPM level and gearbox torque occur on pumping units that are operating improperly counterbalanced. Operating "weight heavy" (i.e., too much CBE) during the upstroke, or operating "rod heavy" (i.e., not enough CBE) during the downstroke, will frequently cause radical increases in the prime mover RPM.

PERMISSIBLE ENVELOPES

Equation

Since torque on the gearbox is not in a single direction, a method of evaluating the effect of the torque direction is needed. Mathematically, torque direction is indicated by changing the sign of the gearbox torque. The following equation then results when the sign change of the net torque is included in the preceding equation.

W = ({ (+/- Tn) + [M * Sine(Theta - Tau)]} / TF) + B

Note that changing from an understood positive (+) sign to a combination of (+/-) signs in front of the TORQUE variable is the only change to the original equation. This is an innocuous-appearing change; however, it doubles the number of curves which will be generated. It thus doubles the number of potential limits which will be applied to a particular pumping unit.

This formula can be written as two formulas, for clarity. The first formula, which is the same as in the work of Gault (updated for later units), used for finding the polished rod load which is the limit in the positive torque direction, is:

W = ({ (+ Tn) + [M * Sine(Theta - Tau)]} / TF) + B

The second formula, which is the new development in this paper, used to find the polished rod load which is the limit in the negative torque direction, is:

W = ({ (- Tn) + [M * Sine(Theta - Tau)]} / TF) + B

All these values of the limiting polished rod load, W, are calculated and plotted against polished rod position for one revolution. The resulting curves define what I have termed the "Permissible Envelope" of polished rod load.

As long as the polished rod load stays within the respective permissible envelopes during the upstroke and downstroke, the gearbox will not exceed the gearbox torque rating in EITHER the positive or negative torque direction.

Examples

Permissible envelopes for four different pumping units are shown in figures 7-A through 10-D. Four different CBE levels are applied to each of the units; 10000#, 20000#, 25000#, and 30000#. The four pumping units used are all API size 640-365-168, and the geometries are:

1) Class I rear mounted geometry pumping unit with phased crank counterbalance
   (Class I w/Phased CBE)
   Figure 1 and Figures 7-A through 7-D.

2) Class I rear mounted geometry unit; with slight modifications to geometry
   (Class I (Mod. I))
   Figures 8-A through 8-D.

3) Class I rear mounted geometry unit
   (Class I)
   Figures 9-A through 9-D.

4) Class III front-mounted geometry unit
   (Class III Front-Mtd.)
   Figures 10-A through 10-D.

Figure 1 is an example computer printout for the Class I geometry pumping unit with phased crank counterbalance, at 10000# CBE. To save paper and space, the printout is in 15 degree increments of crank pin angle; but calculations are made and plotted every 1 degree for accuracy.

The permissible load range is based on subtracting the (maximum value of) downstroke minimum polished rod load from the (minimum value of) upstroke maximum polished rod load. (Upstroke torque factors are positive; downstroke torque factors are negative.) For illustration purposes, from Figure 1, at 15 degree intervals, the values would be 17979# at the 75 degree upstroke crank angle, minus 1698# at the 285 degree downstroke crank angle; for a 16281# permissible load range.

The printout, calculated every 1 degree for accuracy, shows 16280#.

Span

The permissible envelopes' span, or range, is based on subtracting the highest value of minimum rod load permitted, 1974# at 105 degrees, from the lowest value for the maximum rod load permitted, 16344# at 285 degrees; for 14370# permissible envelope span. The value shown on the printout, is 14351#, again based on 1 degree interval calculations for better accuracy, .

The portion of Figure 7-A labeled "UPSTROKE" is a graphic display of the upstroke maximum and minimum rod loads permissible. Note that the structure rating of 36500# limits the maximum load line, and that the zero baseline limits the minimum load. We now have a graph that truly defines the permissible rod loads during upstroke.

If the upstroke loads stay within the two lines, the gearbox is operating within rated torque. Conversely, if the upstroke loads are beyond the boundaries of either of the two lines, the gearbox is operating at a torque overload, and may be subject to premature failure.

Similarly, the portion of Figure 7-A labeled "DOWNSTROKE" is a graphic display of the downstroke minimum and maximum rod loads permissible. If the downstroke loads stay within the two lines, the gearbox is operating within rated torque; while loads outside either line mean that the gearbox is operating above rated torque.

The portion of Figure 7-A labeled "COMPOSITE" is an overlay of the upstroke and downstroke envelopes on the same graph. If the polished rod loads stay within all four lines, the gearbox is operating within rated torque. Loads which are between the two maximum lines or between the two minimum lines must be evaluated further, before a determination of overload can be made.

Effect of Unit Geometry and CBE

Comparison of Figures 7-A, 8-A, 9-A, and 10-A show some effect of geometry on the shape of the permissible envelope. At this very low level of CBE (10000#) on these units, the shape of the first three units' permissible envelopes is about the same. All of them generally slope upward as you look from the left side toward the right side of the graphs. The shape of the Class III units' curves, in Figure 10-D, are significantly different, in that they slope down and to the right.

Comparison of Figures 7-A through 9-D (with each of the three units at 10000#, 20000#, 25000#, and 30000# CBE) reveals that, as CBE increases, the three different Class I units' permissible envelopes slope more and more sharply up and to the right. Another effect is that the throat, or distance between the lines, narrows, reducing the work area available for a dynamometer card.

The Class III units' permissible envelopes, in Figures 10-A through 10-D, slope more and more sharply down and to the right as CBE increases. The throat area at the left side begins restricting until, at 30000# CBE, it is almost "pinched off" at the left side and in the middle. The amount of available area for a dynamometer card at 30000# CBE is extremely low. This permissible envelope allows application to a more limited family of dynamometer cards without careful analysis to be sure that the gearbox is not overloaded.

Figure 2 is a worksheet with the permissible load range and permissible envelope range for the four units at the four different CBE values.

Figure 3 is a graphic display of the permissible load range values of Figure 2. It provides a quick comparison of how the permissible load range changes as CBE and pumping unit geometry changes. This graph illustrates that both have a large effect on the response of a pumping unit to a particular dynamometer card load and shape.

Figure 4 is a graphic display of the permissible envelope spans of Figure 2. This is an even more dramatic display of the effect of CBE level and pumping unit geometry on the ability of a unit to respond to a particular pumping situation.

Counterbalance Effect Discussion

Any discussion of permissible loads and permissible envelopes is incomplete without counterbalance effect, or "CBE". API Spec. 11E provides a general definition of CBE, paraphrased as:

$$\text{CBE} = \frac{\text{counterbalance moment}}{\text{torque factor for the crank pin angle of interest}}$$

Many people, myself included, tend to talk of CBE as though it were a single, fixed value. This is because most of the time we are only interested in the CBE at either 90 or 270 degrees. One of these two angles, depending on the pumping unit geometry and rotation direction, is used for specifying CBE level when buying a unit, or changing CBE to properly counterbalance the unit.

Frequently, what is not brought out is that "CBE" is a continually changing value that is dependent on the crank pin angle. For our purposes, then, this continually varying CBE amount can be plotted on the permissible envelope curves, as in Figure 5, for a Class III Front-Mtd. unit.

We observe that there is a radical difference in the CBE level as the unit is rotated through one revolution. At the 90 degree crank pin angle for this unit, the polished rod position is calculated to be .576. From Figure 5, at this position in the upstroke, the CBE line is going through the 30000# "CBE" level of the unit.

At other rod positions, CBE varies from a negative amount to more than the structural rating. (Please note that this is a normal occurrence.) In the composite portion of Figure 5, it is observed that there is also a radical difference in CBE lines between upstroke and downstroke.

When we look at the upstroke and downstroke portions of Figure 5, the CBE lines functionally represent lines of zero gearbox torque. That is, if the polished rod loads at all crank pin angles precisely duplicated the CBE lines, the gearbox torque required (ignoring friction and reality!) would be zero.

When the polished rod load is above the CBE line on the upstroke, positive gearbox torque is required, and the pumping unit will slow down. When the polished rod load is below the CBE line, negative gearbox torque is required, and the pumping unit will speed up.

Similarly, during the downstroke, when the polished rod load is above the CBE line, negative gearbox torque is required. When the polished rod load is below the CBE line, positive gearbox torque is required.

One of the more interesting things on the Figure 5 upstroke curve is that there is an area of "enforced negative torque". Between rod positions of about .05 to .32, unless the polished rod load is ABOVE structure rating, the gearbox will be forced into negative torque, and the prime mover will be forced into an overspeed condition.

Noise Makers

Besides a speed (SPM) change in a pumping unit when gearbox torque changes direction (sign), another effect may be noticed. There may be a regular, low-pitched thumping noise if the net torque curve goes through a zero torque position. This is due to the backlash, or clearance between meshing gearbox teeth; necessary for proper lubrication and operation of gearboxes.

This effect may be verified by drawing a circle, then marking the crank pin locations at which the noise occurs, while taking a dynamometer card. Next, a net torque analysis of the dynamometer card is performed. The thumping noises will quite frequently correlate directly with the crank pin angles at which the gearbox torque curve is going through a zero torque point. Typically, the steeper the torque curve as it goes through the zero torque point, the louder the noise will be.

The cause of noise that occurs at zero torque positions is normally that the gear tooth load is changing from one side of the tooth to the other, while reversing torque direction. This reversal may be noisy, but generally is not harmful, since it occurs at zero, or low, torque areas. This can happen at any CBE level, since it is more dependent on the pumping unit geometry and dynamometer card shape than other factors, for a given installation.

If the low-pitched thumping noises do not occur at zero torque locations, further investigation may be warranted. There may be a downhole fluid pound, something loose on or around the unit, or other cause of the noises.

Comparison of Permissible Envelopes

Finally, Figure 6 is a comparison of the composite permissible envelopes of Figures 7-D, 8-D, 9-D, and 10-D. Study of it provides an interesting contrast, and helps understand what the numbers and graphs of Figures 2, 3, and 4 mean; in terms of what the response to a typical pumping condition will be at higher CBE levels. A summary of basic observations is provided below.

The unit labeled "Class I w/Phased CBE" has a relatively flat permissible envelope, with a wide span between the limiting lines. This unit will accommodate a wider variety of dynamometer cards, with reduced danger of gearbox torque overload, when compared with the other three units.

The unit labeled "Class I w/Mod. I" has a tilted permissible envelope, with some reduction in the span between limiting lines. This unit accommodates a narrower variety of dynamometer cards, with more danger of gearbox torque overload, when compared with the first unit.

The unit labeled "Class I" has an even more tilted permissible envelope, with further reduction in the span between the limiting lines. This unit accommodates a narrower variety of dynamometer cards, with more danger of gearbox torque overload, when compared with the first two units.

The unit labeled "Class III" has an abruptly tilted permissible envelope, with substantial reduction in the span between the limiting lines. This unit accommodates the least variety of dynamometer cards, with the most danger of gearbox torque overload, when compared with the other three units.

SUMMARY

To summarize, in the order of presentation of the four unit geometries: the tilt of the permissible envelopes becomes more pronounced, and the span between the maximum and minimum permissible envelope lines more reduced. This makes it progressively more difficult to pump a wide variety of well conditions and dynamometer cards without performing a complete analysis of the system.

Please note that, since pumping conditions occur in an infinite variety, this summarization necessarily paints with a broad brush. When a particular pumping unit geometry and CBE level generate a permissible envelope that the dynamometer card fits well, then that unit would be expected to perform well.

Conversely, when a particular pumping unit geometry and CBE level generate a permissible envelope that the dynamometer card does not match well, then that unit would be expected to perform badly.

CONCLUSIONS:

The Permissible Envelope provides understanding of why pumping units experience both positive and negative gearbox torque. Permissible envelopes also provide more complete definition of acceptable pumping unit rod loads for a particular pumping unit than has been available in the past.

REFERENCES:

1 Gault, Robert H.: "Permissible Load Diagrams for Pumping Units", Seventh Edition, Southwest Petroleum Short Course, Lubbock, Texas, April 1960

2 "Specification for Pumping Units", API Specification 11E, 16th Ed. (1989)

PERMISSIBLE LOAD ANALYSIS OF:

CLASS I w/Phased CBE ROTATING CLOCKWISE

CRANK PIN ANGLE	POLISHED ROD POSITION	TORQUE FACTOR	C'BAL. EFFECT, POUNDS	MAXIMUM ROD LOAD PERM	MINIMUM ROD LOAD PERM.
30	.018	24.216	8976	35406	0
45	.074	47.351	8587	22103	0
60	.162	64.486	8801	18725	0
75	.271	73.926	9322	17979	665
90	.389	76.341	10000	18383	1617
105	.506	73.781	10649	19323	1974
120	.617	68.347	11044	20408	1680
135	.718	61.454	10955	21369	540
150	.808	53.678	10178	22101	0
165	.884	44.791	8546	22834	0
180	.946	33.713	5733	24717	0
195	.987	18.396	-532	34259	0
210	1	-3.519	60594	36500	0
225	.973	-31.305	12885	33330	0
240	.903	-57.908	9778	20830	0
255	.797	-76.219	9048	17445	651
270	.67	-85.349	8966	16464	1467
285	.535	-87.396	9021	16344	1698
300	.401	-84.09	9014	16625	1403
315	.276	-76.219	8871	17268	474
330	.166	-63.933	8578	18588	0
345	.079	-47.143	8129	21705	0
360	.022	-25.983	7379	32010	0
375	0	-1.419	-9283	36500	0

ABOVE GENERATED WITH:

COUNTERBALANCE EFFECT	=	10000 LB
STRUCTURAL UNBALANCE	=	200 LB
GEARBOX TORQUE RATING	=	640000 INCH-LB
STRUCTURE RATING	=	36500 LB
CALCULATED STROKE LENGTH	=	168.223 INCH

GEOMETRY OF UNIT:

A	C	P	R	H	I	G	PHASE
184.750	120.625	185.000	49.625	293.000	172.000	121.000	-14.00

PERM. LOAD RANGE (AT 1 DEGREE INTERVALS) = 16280 LB
PERM. LOAD ENVELOPE (AT 1 DEGREE INTERVALS) = 14351 LB

Figure 1

PERMISSIBLE LOAD RANGE / PERMISSIBLE LOAD ENVELOPE

CBE, #	CLASS I UNIT W/PHASED CBE PERM. LOAD: RANGE	ENVEL.	CLASS I UNIT W/MOD. I PERM. LOAD: RANGE	ENVEL.	CLASS I UNIT PERM. LOAD: RANGE	ENVEL.	CLASS III UNIT FRONT-MTD. PERM. LOAD: RANGE	ENVEL.
10000	16280	14351	13892	13665	14120	12937	10972	6707
20000	16459	12472	12157	10925	11504	9549	7549	3149
25000	16467	11470	10539	9246	9832	7601	3196	-992
30000	13025	8894	7524	6889	8003	5565	-1770	-5680

Figure 2

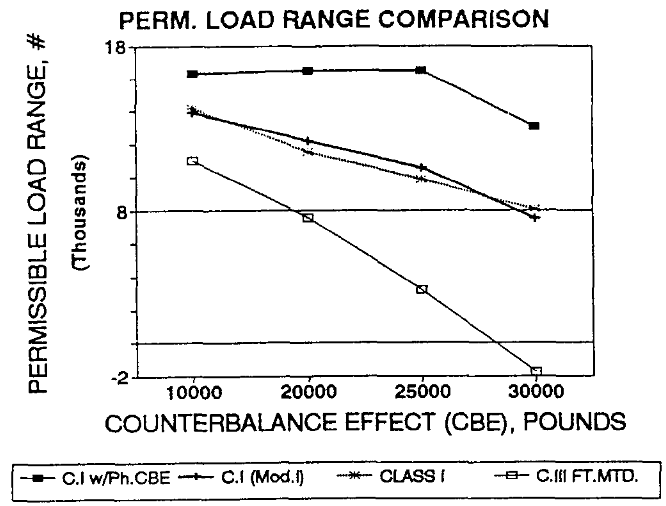

Figure 3

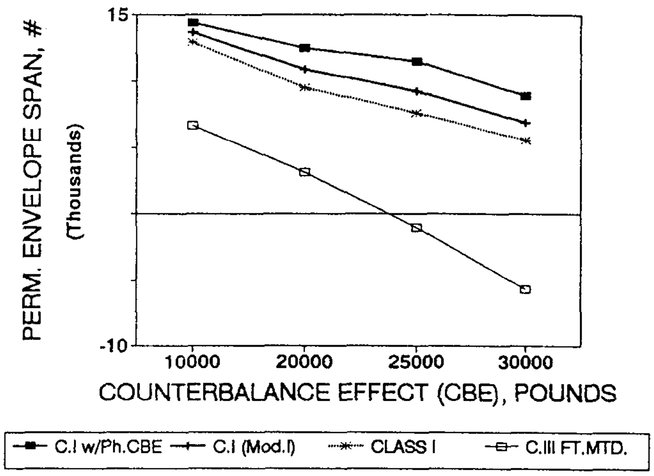

Figure 4

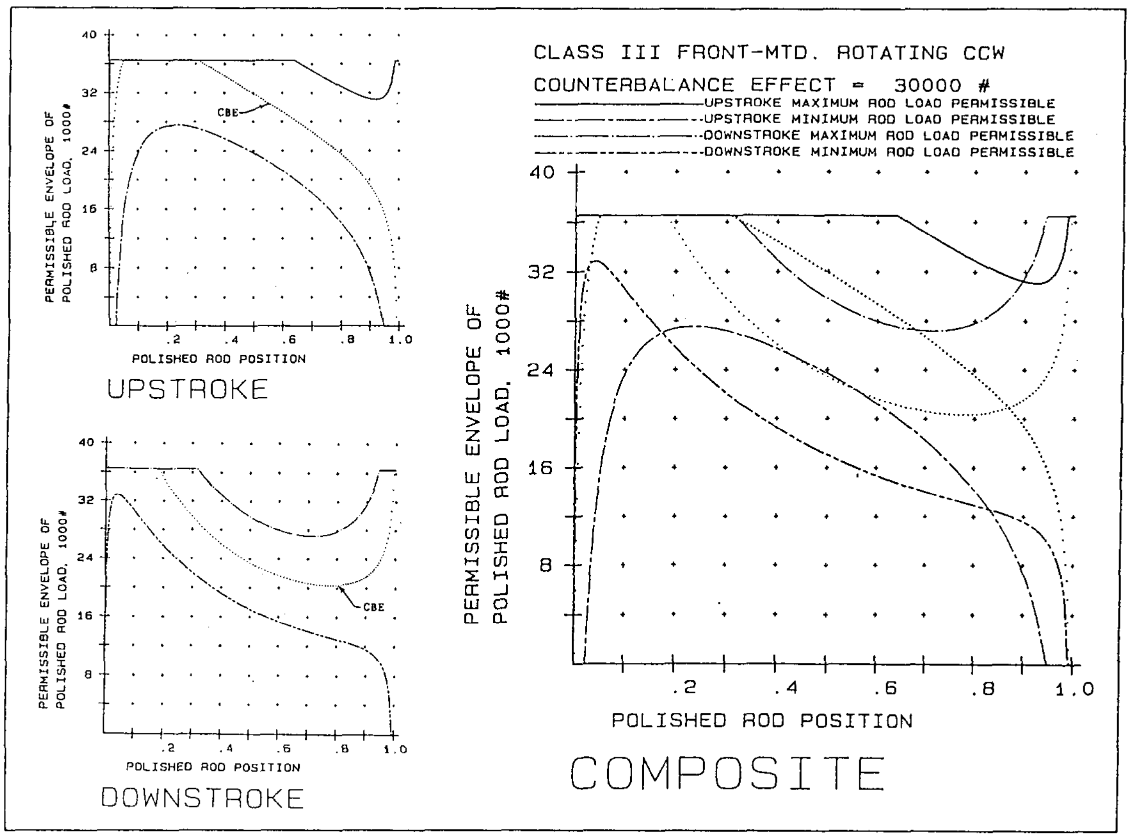

Figure 5

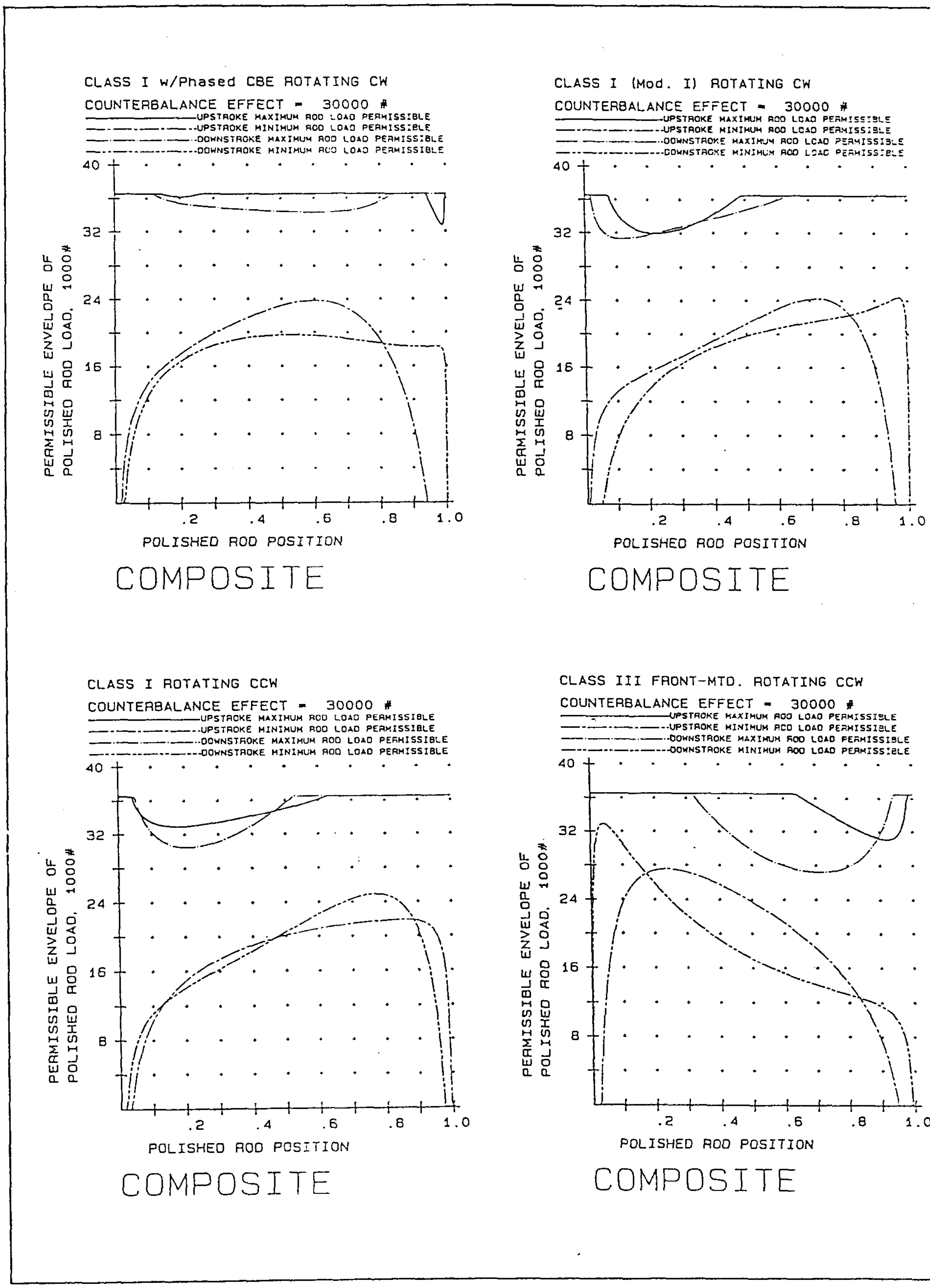
CLASS I w/Phased CBE ROTATING CW
COUNTERBALANCE EFFECT = 30000 #
UPSTROKE MAXIMUM ROD LOAD PERMISSIBLE
UPSTROKE MINIMUM ROD LOAD PERMISSIBLE
DOWNSTROKE MAXIMUM ROD LOAD PERMISSIBLE
DOWNSTROKE MINIMUM ROD LOAD PERMISSIBLE
PERMISSIBLE ENVELOPE OF POLISHED ROD LOAD, 1000#
POLISHED ROD POSITION
COMPOSITE
CLASS I (Mod. I) ROTATING CW
COUNTERBALANCE EFFECT = 30000 #
UPSTROKE MAXIMUM ROD LOAD PERMISSIBLE
UPSTROKE MINIMUM ROD LOAD PERMISSIBLE
DOWNSTROKE MAXIMUM ROD LOAD PERMISSIBLE
DOWNSTROKE MINIMUM ROD LOAD PERMISSIBLE
PERMISSIBLE ENVELOPE OF POLISHED ROD LOAD, 1000#
POLISHED ROD POSITION
COMPOSITE
CLASS I ROTATING CCW
COUNTERBALANCE EFFECT = 30000 #
UPSTROKE MAXIMUM ROD LOAD PERMISSIBLE
UPSTROKE MINIMUM ROD LOAD PERMISSIBLE
DOWNSTROKE MAXIMUM ROD LOAD PERMISSIBLE
DOWNSTROKE MINIMUM ROD LOAD PERMISSIBLE
PERMISSIBLE ENVELOPE OF POLISHED ROD LOAD, 1000#
POLISHED ROD POSITION
COMPOSITE
CLASS III FRONT-MTD. ROTATING CCW
COUNTERBALANCE EFFECT = 30000 #
UPSTROKE MAXIMUM ROD LOAD PERMISSIBLE
UPSTROKE MINIMUM ROD LOAD PERMISSIBLE
DOWNSTROKE MAXIMUM ROD LOAD PERMISSIBLE
DOWNSTROKE MINIMUM ROD LOAD PERMISSIBLE
PERMISSIBLE ENVELOPE OF POLISHED ROD LOAD, 1000#
POLISHED ROD POSITION
COMPOSITE

Figure 6

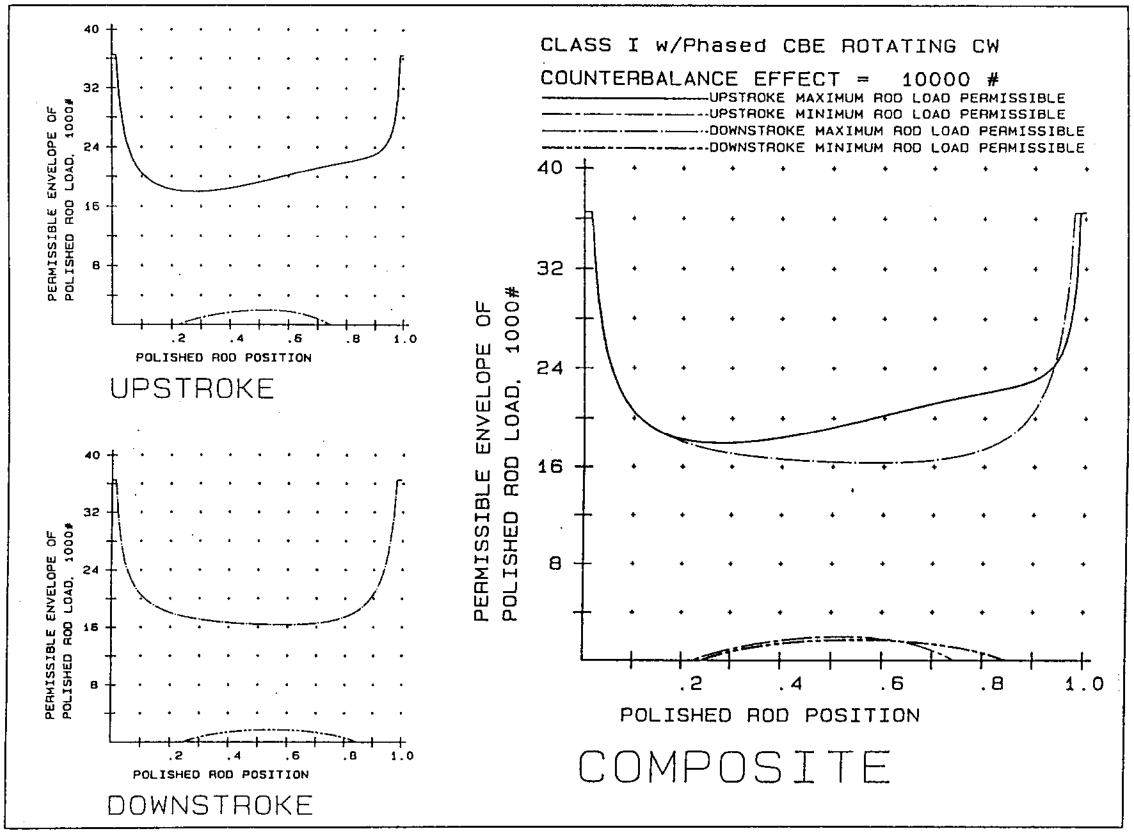

Figure 7-A

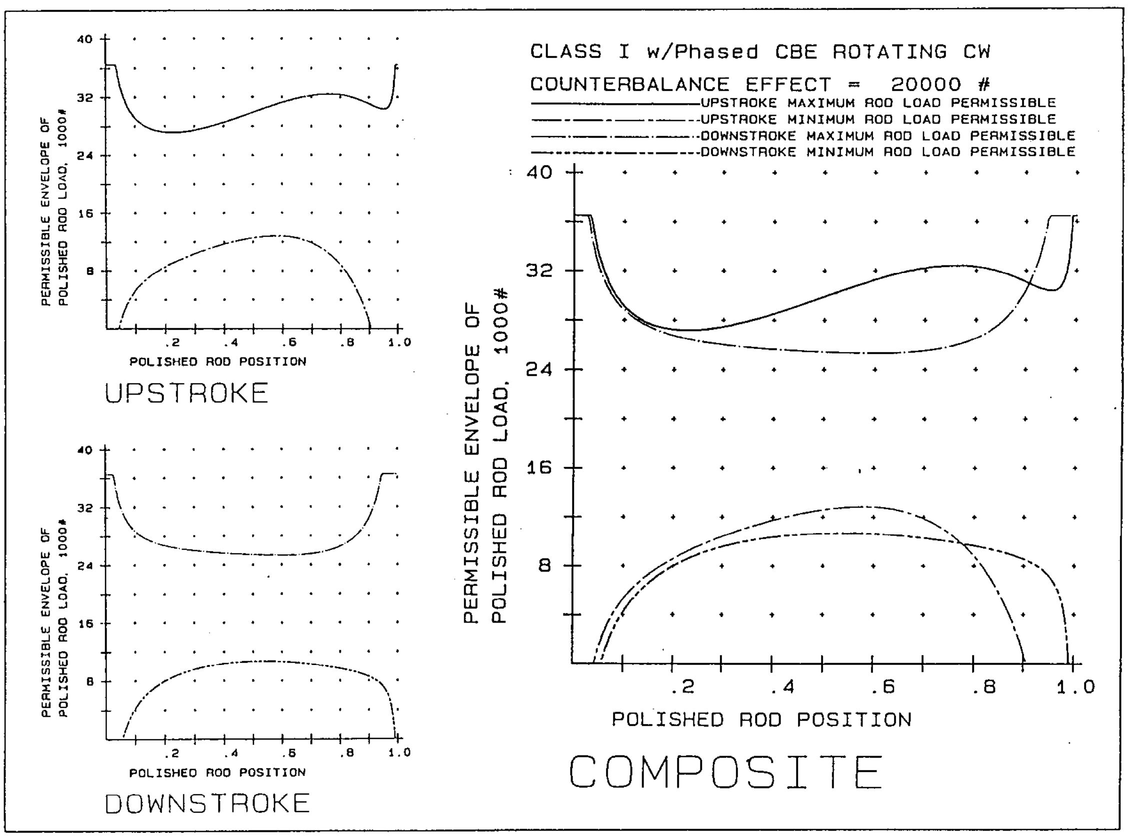

Figure 7-B

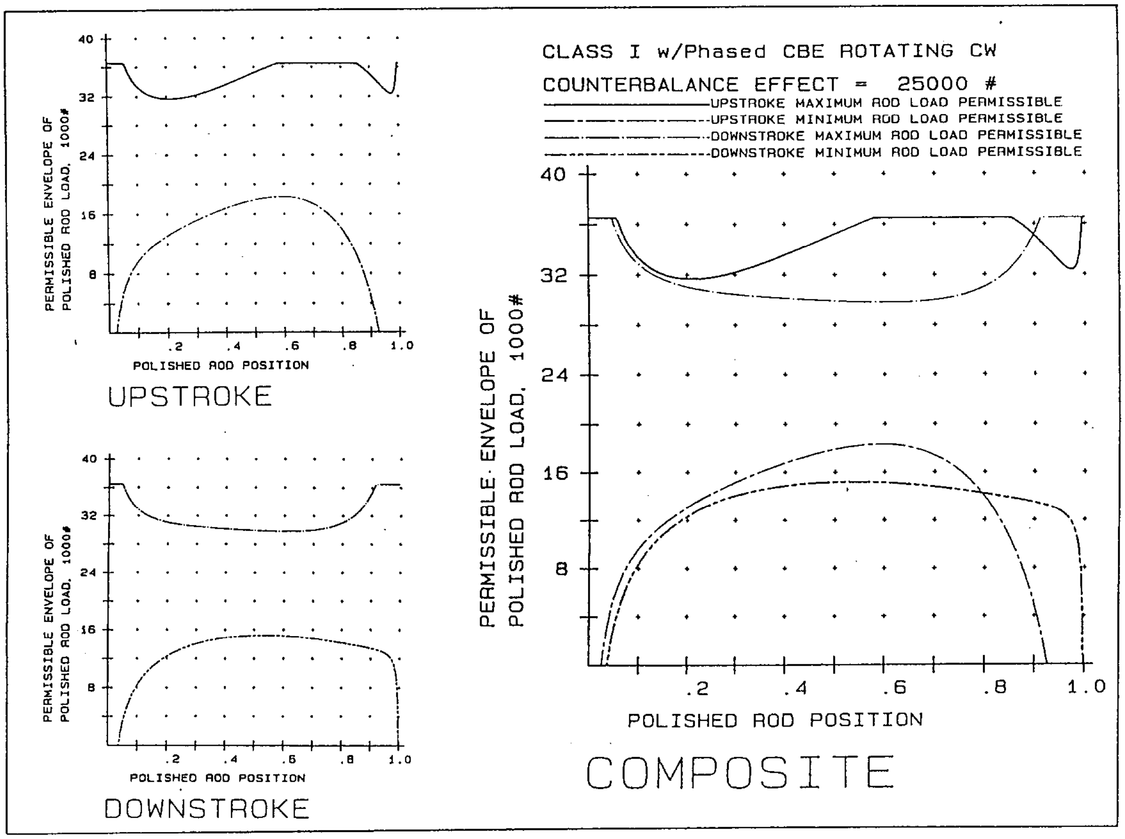

Figure 7-C

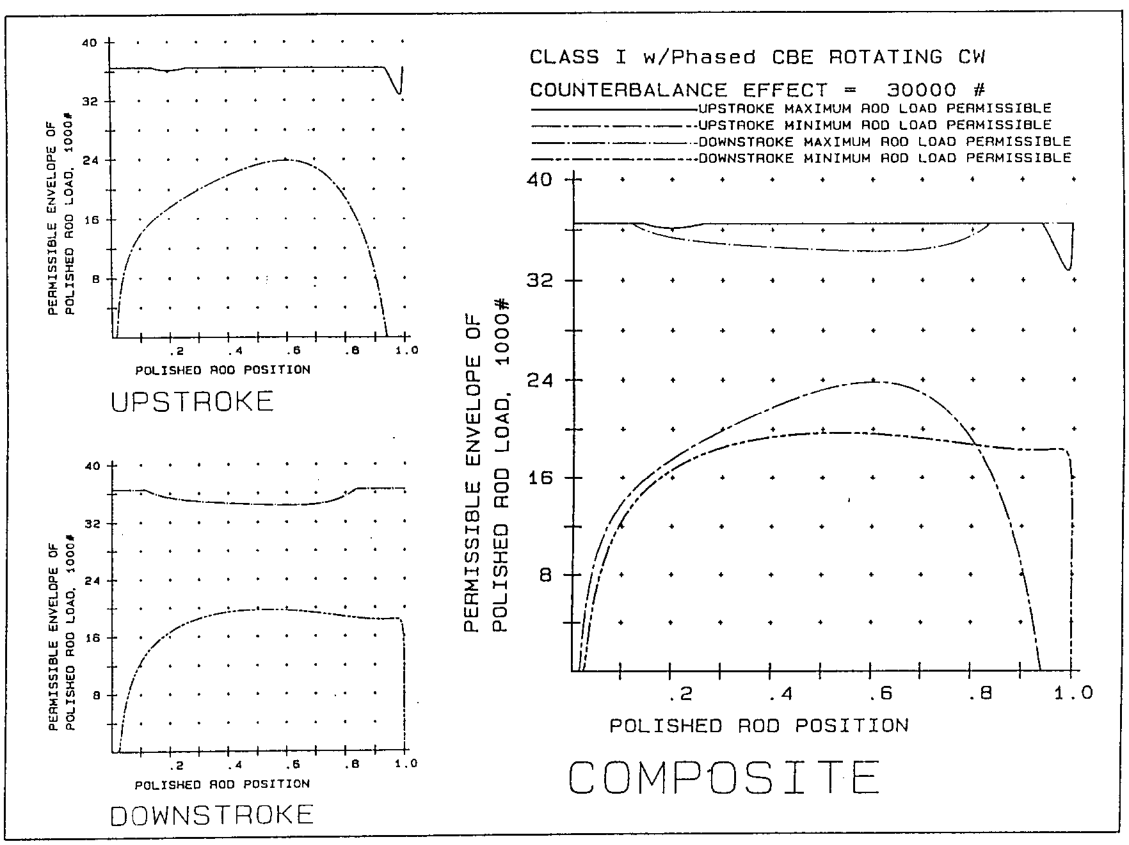

Figure 7-D

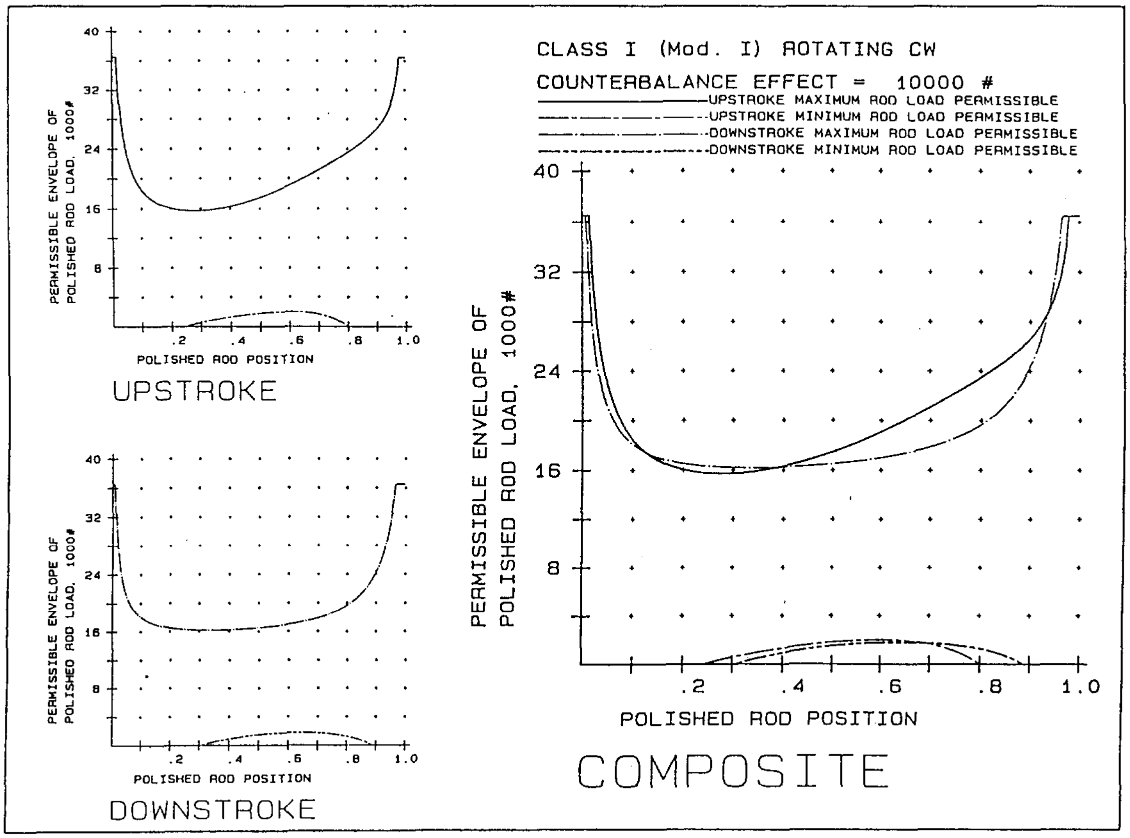

Figure 8-A

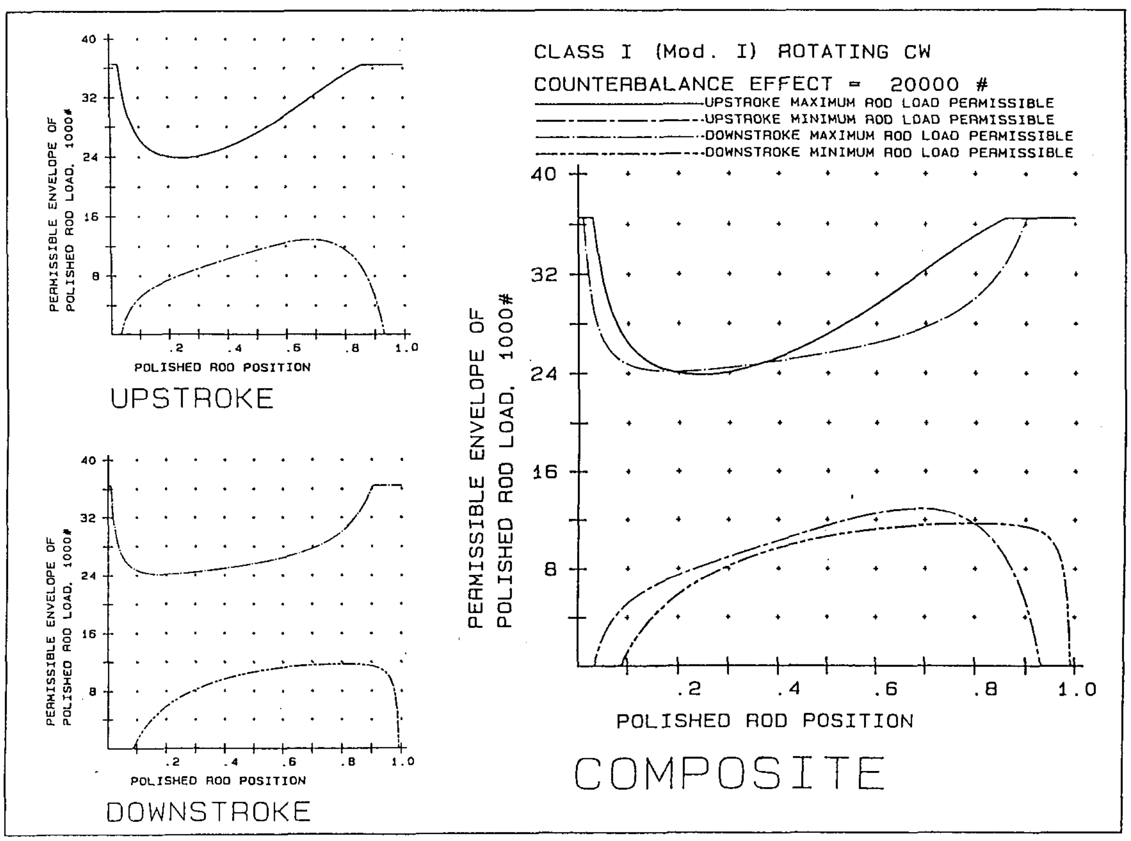

Figure 8-B

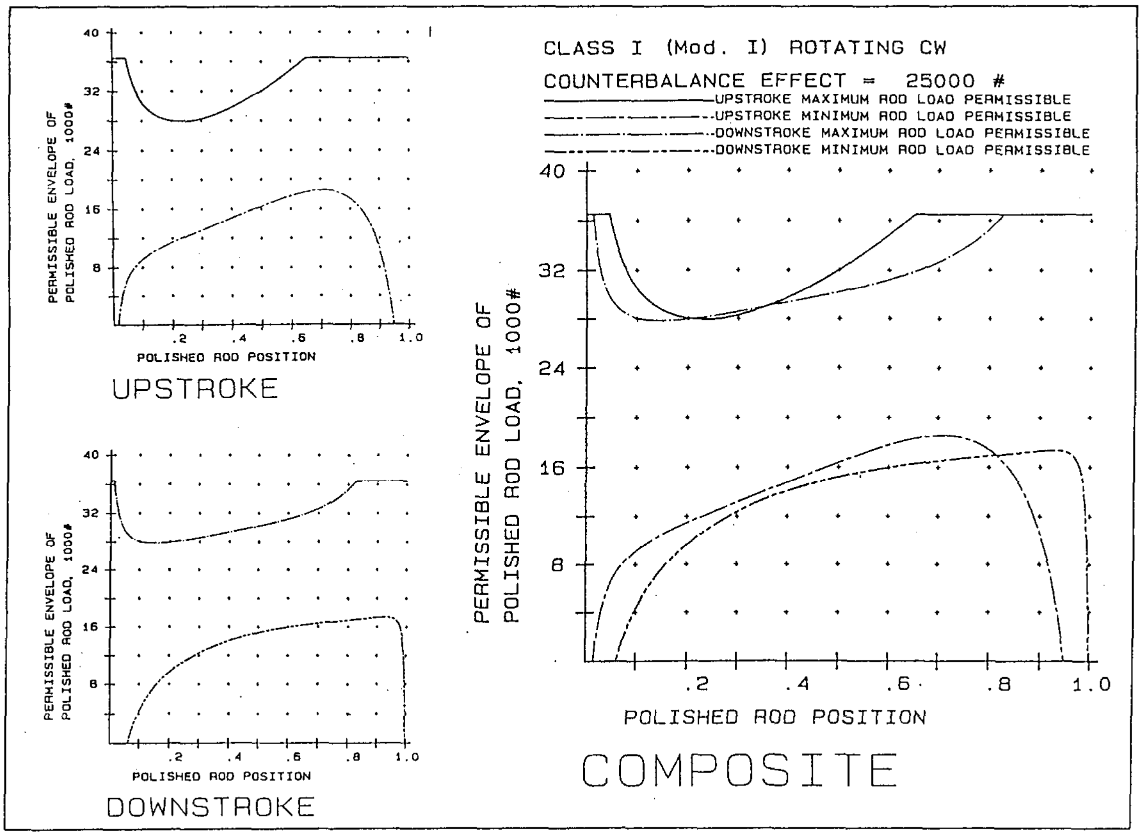

Figure 8-C

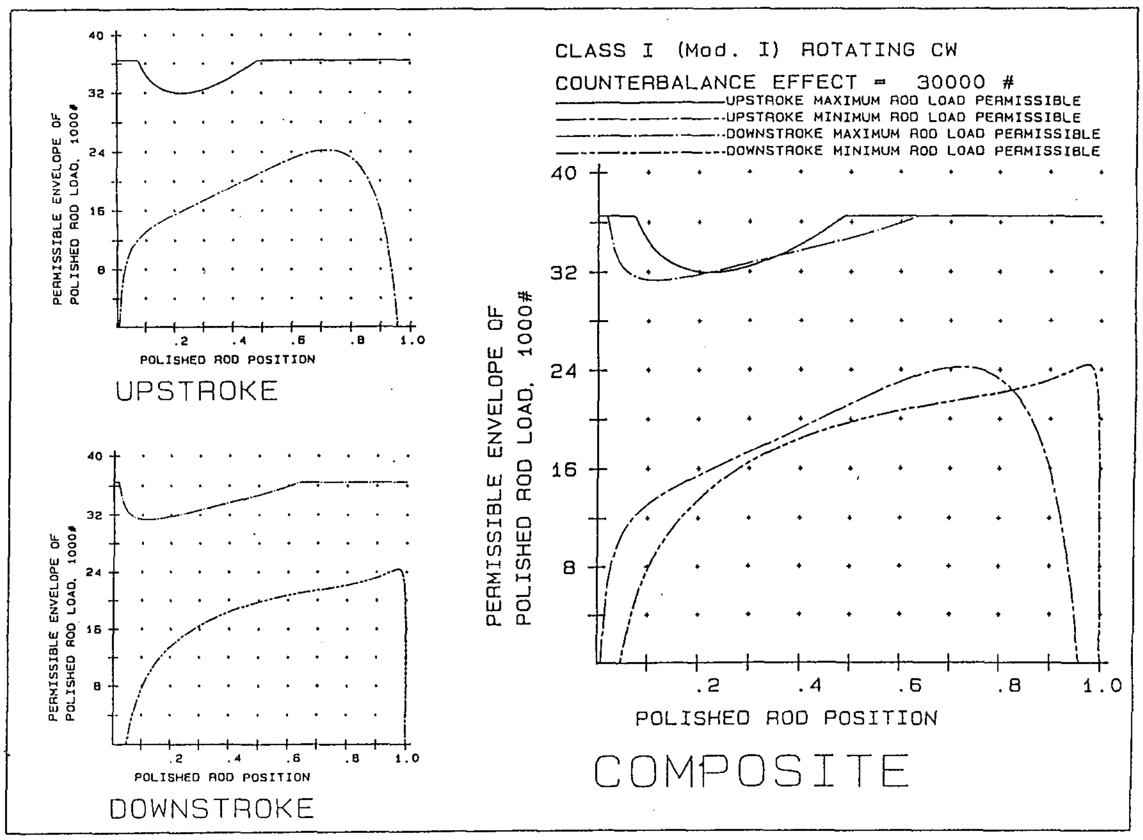

Figure 8-D

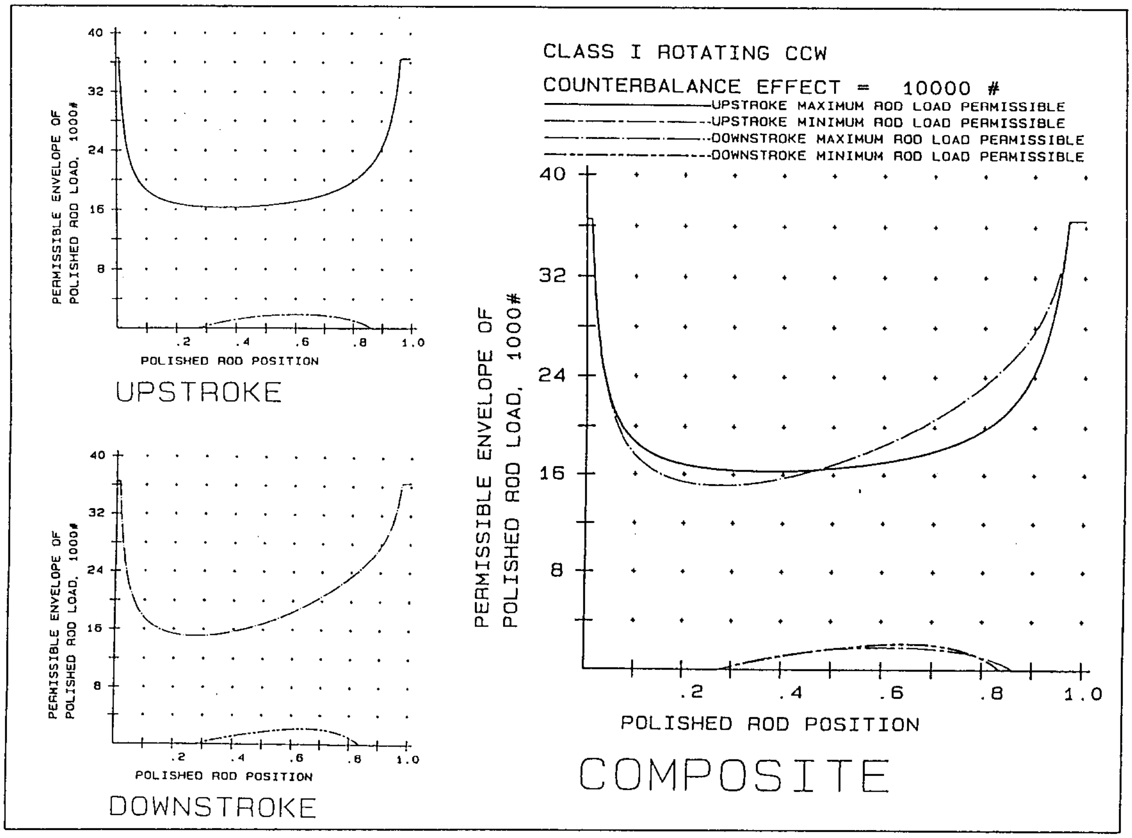

Figure 9-A

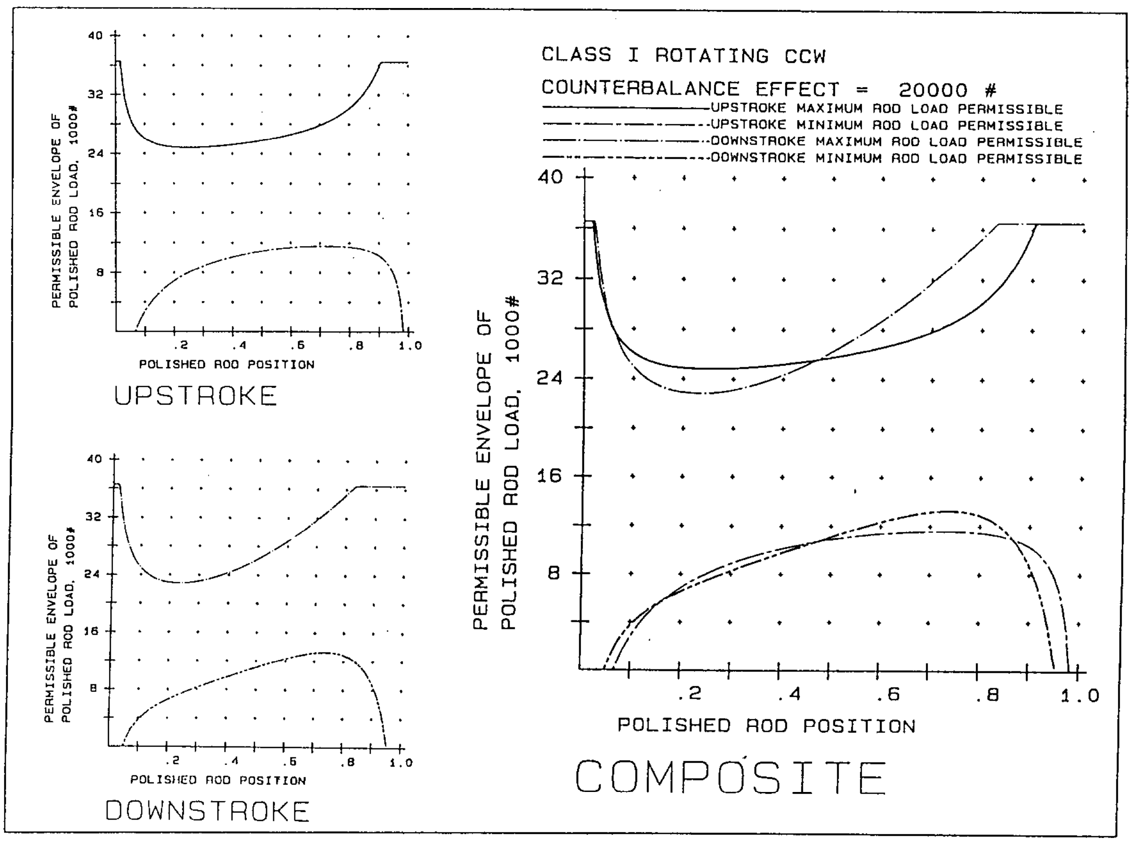

Figure 9-B

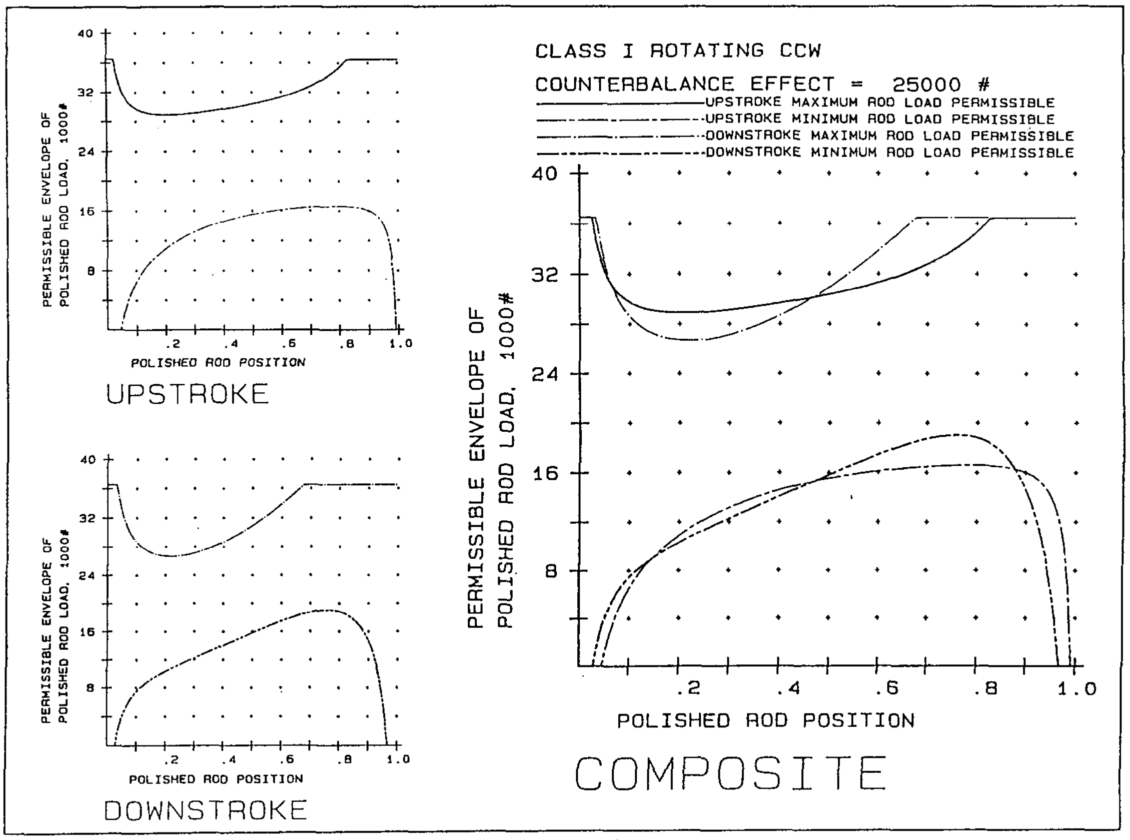

Figure 9-C

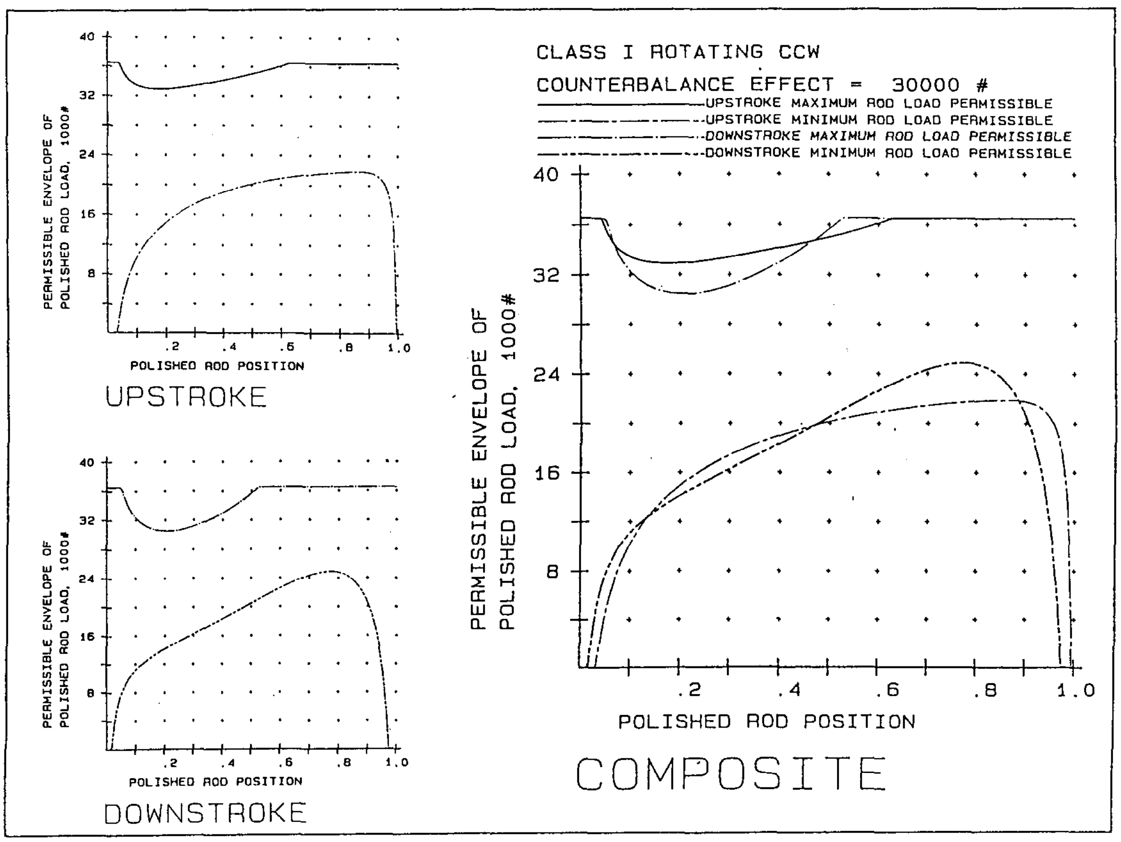

Figure 9-D

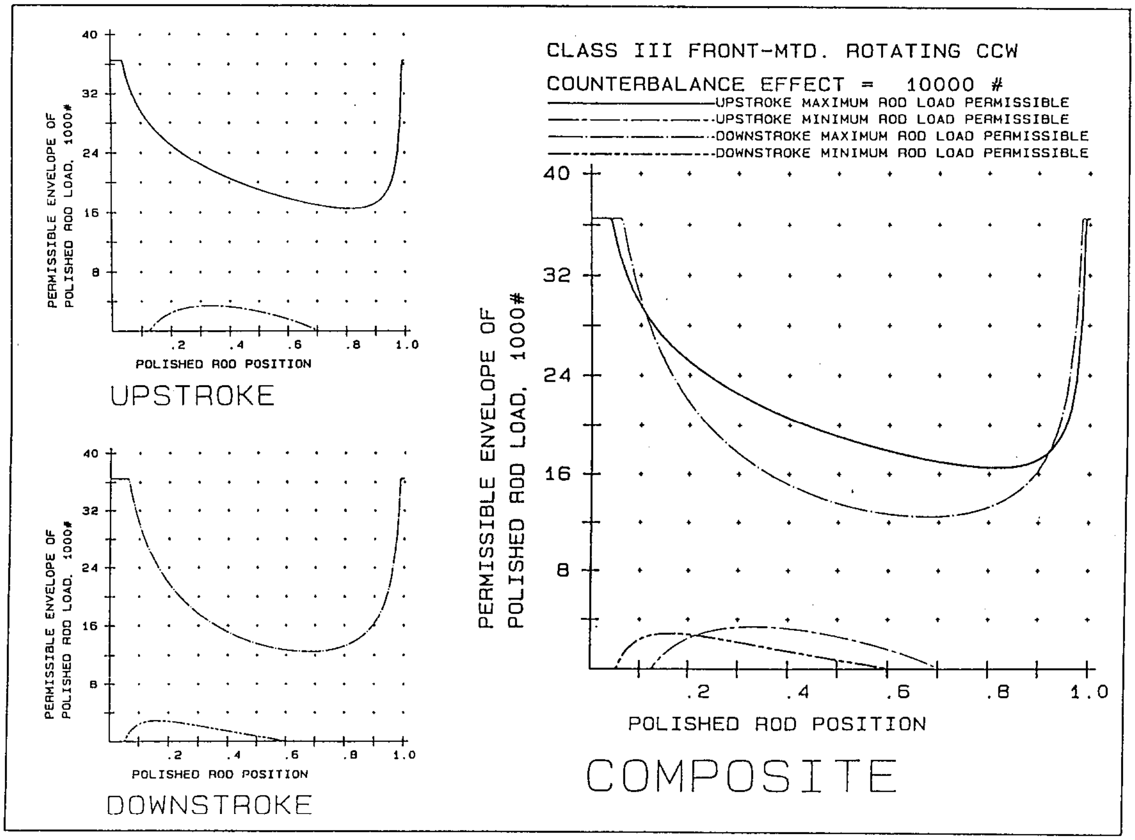

Figure 10-A

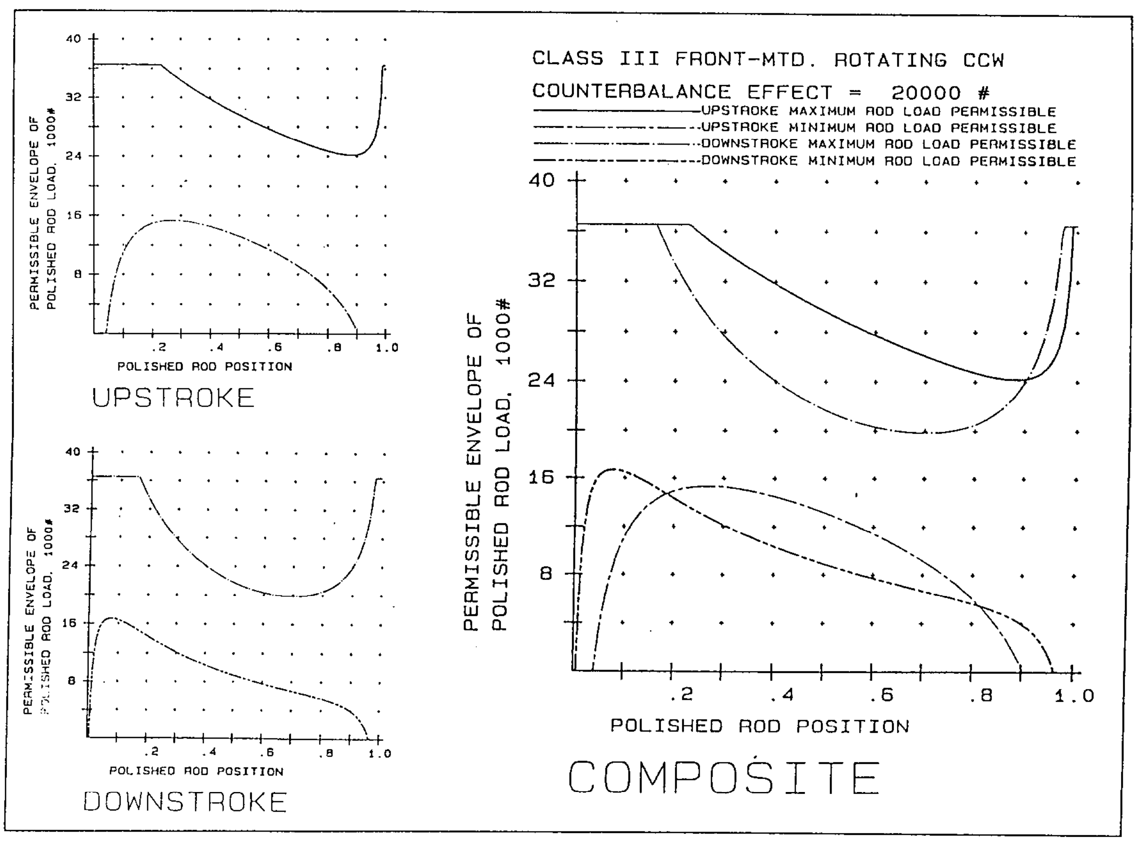

Figure10-B

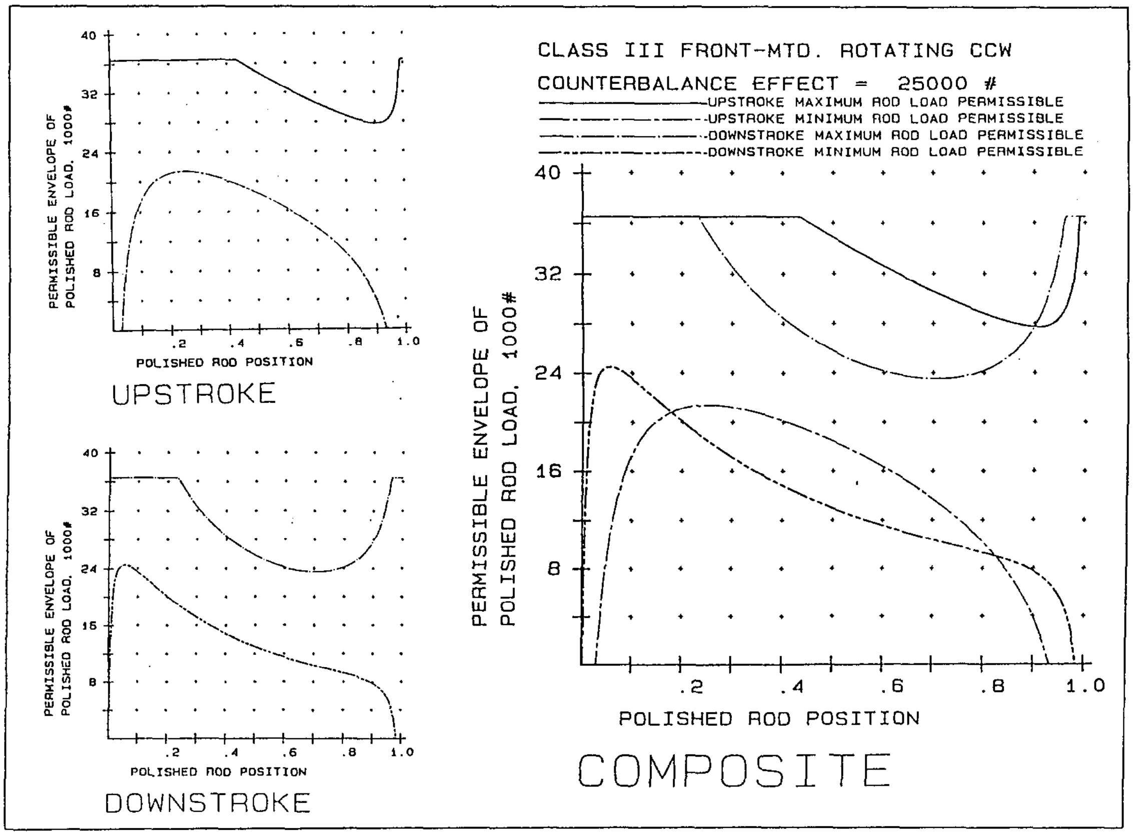

Figure 10-C

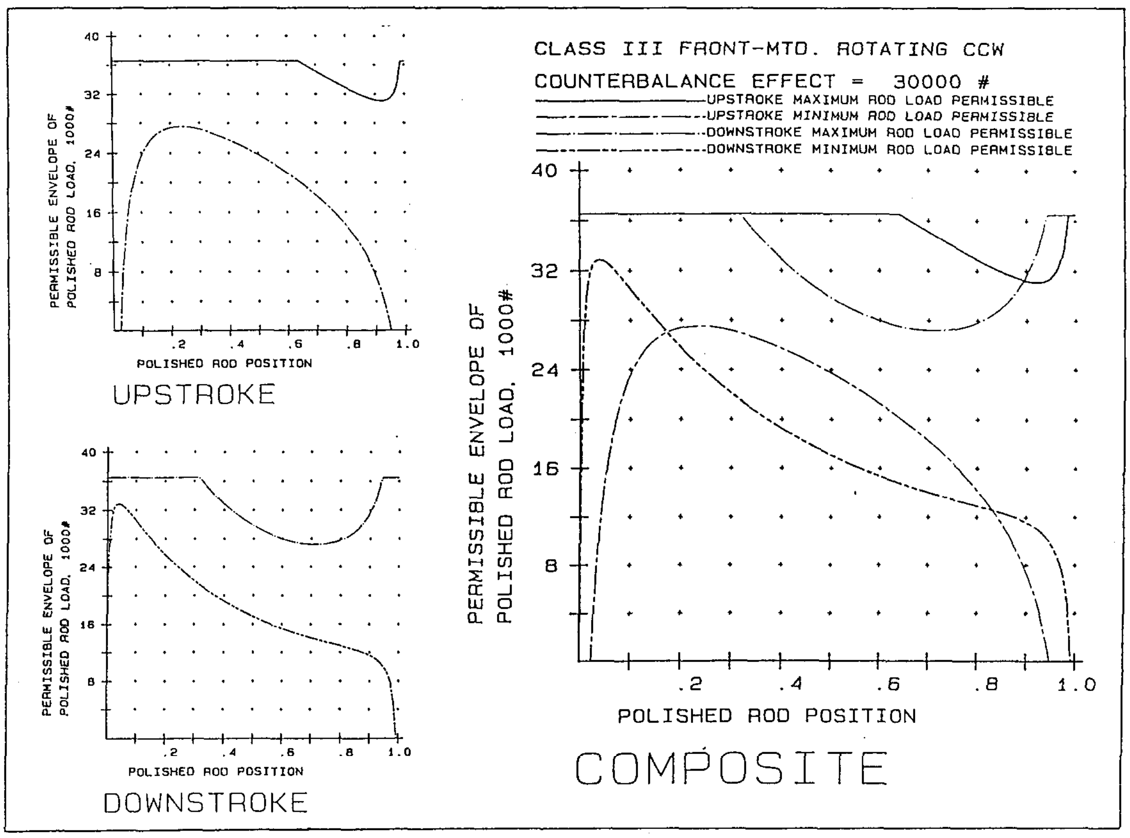

Figure 10-D