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Ltr re our 10-3-72 ltr....submitting a report concerning control rod configurations........ W/Attachments - Tables 1 & 2 & Figures 1 thru 10.
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PLANT NAMES: H. B. Robinson Unit No. 2

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November 10, 1972

Mr. D. J. Skovholt
Assistant Director
Operating Reactors
Directorate of Licensing
U. S. Atomic Energy Commission
Washington, D. C. 20545

50 - 261

H. B. ROBINSON UNIT NO. 2
LICENSE DPR-23
RELATIONSHIPS BETWEEN NUCLEAR HOT CHANNEL FACTORS AND CONTROL AND PART LENGTH CONTROL ROD CONFIGURATIONS

Dear Mr. Skovholt:

In your letter of October 3, 1972, a request was made for the predicted maximum fuel power densities for the worst case control rod configurations which are permissible under the presently allowable control rod insertion limits. The basic question to be answered was whether CP&L's request for reactor operation with a lower F_Q^N would require revised control rod insertion limits. These limits, as specified in Figure 3.10-1 of the Technical Specifications, were originally developed assuming F_Q^N equal to 3.13 and a maximum fuel power density of 17.9 kw/ft at 2,200 Mwt. The proposed reduction in F_Q^N would reduce the maximum kw/ft from 17.9 to 15.8.

Therefore, a study was undertaken to determine if there existed any combination of full length and part length rods which would result in a peak kw/ft greater than 15.8. The fact that any axial offset greater than $\pm$26% would result in a scram and limit the maximum kw/ft was also considered in this analysis (Technical Specification 2.3.1.2.d.1).

METHODS AND ASSUMPTIONS USED

A three dimensional nodal analysis was used to simulate the core power distribution and control rod interactions using 18 axial nodes per assembly. This model is continually being compared with actual operating data from H. B. Robinson and the agreement to date is excellent. For example, Figure 1 compares the calculated and measured assembly relative power at 9,000 MWD/MTU. Except for a few peripheral assemblies, the agreement is within $\pm$3%. Agreement between calculated and measured values has been at least this good throughout Cycle 1.

The calculations for the present study were performed at a core average exposure of 14,000 MWD/MTU. The conclusions drawn from calculations at this exposure are valid through the end of Cycle 1, since the current exposure is approximately 13,000 MWD/MTU and the end of cycle is projected to be at 15,000 MWD/MTU. The validity of the insertion limits was not checked for Cycle 2. It is intended to provide this information after the core loading pattern for Cycle 2 has been firmly established.

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In addition, this analysis was directed at investigating normal and anticipated transients. Abnormal occurrences such as those identified in Technical Specification 3.10.2 are not considered, since the requirement is to determine the peaking factors for all such occurrences with the moveable incore detectors. Due to the fact that only transient situations were being investigated, the xenon distribution used in the calculations is consistent with the power distribution during our normal operation. It was assumed that the xenon did not have time to redistribute during the time required to move the control rods. Prolonged operation with control rods inserted would result in xenon redistribution; however, this mode of operation is not anticipated. Furthermore, this assumption is conservative. Examples will also be shown where the axial distribution of xenon is oscillatory just prior to control rod insertion.

Due to the use of a nodal analysis in the calculations, there are two additional factors which must be applied to the calculated F_Q^N. First, there is an assembly local peaking factor which must be applied, since the intra-assembly peaking is not considered in a nodal calculation. The assembly local peaking factor was assumed to be a conservative 1.10 in this analysis. A Westinghouse quarter core, rod by rod PDQ calculation was the basis for this assumption. The second factor considered was the possibility of underestimating the axial peaking factor due to the pointwise calculation being applied over eight inches of core when 18 axial nodes are used. Figure 2 illustrates this point. After plotting the axial peaking factors for a number of cases, it was found that a value of 0.05 added to the calculated F_Q^N would cover the worst possible case of underestimating the peaking.

An additional assumption employed in these calculations is the use of only 4 of the 8 part length control rods. The location of these rods is shown in Figure 3. These rods were chosen because the start-up tests were performed with these rods. CP&L has been granted a change in our Technical Specifications to permit movement of part length rods in groups of four. With the use of an 8 part length control rod bank, rod motion must be operationally restricted due to the large axial offset produced by that mode of operation.

RESULTS AT 100% POWER

Figure 4 is a reproduction of Figure 3.10-1 given in the Technical Specifications. This figure shows that control bank D is permitted to range from 228 steps (all out condition) to 107 steps at 100% power. Power distributions were calculated for four positions of bank D in this range and for six positions of a 4 part length rod group at each of these four bank D positions. Table 1 shows the 24 combinations of full length and part length rod configurations which were considered. Also shown are the axial offset and peak kw/ft at each of the 24 combinations. These data were used to construct Figures 5 and 6.

It can be seen from Figure 5 that the maximum fuel power density for the worst combination of full length and part length rods using present Technical Specifications limits is less than 13 kw/ft. The figure also shows a trend of increasing kw/ft with insertion of bank D. When part length rods are inserted, holding D bank at a constant insertion, the peak kw/ft increases to a maximum value around 125 to 150 steps and then rapidly decreases. More importantly, however, Figure 5 shows that there is no combination of full length and part length rods which would result in the peak kw/ft exceeding 15.8 at 100% power. Moreover, there is a factor of at least 1.2 between the calculated maximum kw/ft and the allowed maximum of 15.8 kw/ft.

The axial power shape for cases A3, B3 and C3 are shown in Figures 6, 7 and 8. These figures show the core average F_Q^N versus axial node, and in addition, F_Q^N is plotted for that assembly which has the peak F_Q^N. Locations of the full and part length rods are indicated. The assembly local peaking factor and the nodal correction factor are not included in the plotted values of F_Q^N, since the purpose of these figures is to merely show the shape of the axial power.

An additional safety margin, which limits the maximum fuel power density, is provided by the axial offset scram signal contained in the over-power and over-temperature ΔT protection circuits. Figure 9 shows the calculated axial offset as a function of D bank and part length bank position. The axial offset tends to vary with D bank and part length bank insertion in the same manner as the maximum kw/ft. That is, the axial offset increases with D bank insertion and peaks with the part length rods in the range of 125 to 150 steps. It is noted that the -26% offset limit greatly reduces the permissible range of control configurations where the largest values of kw/ft occur. This fact can be seen in Figure 7 where the -26% offset limit has been superimposed on the graph of kw/ft versus control configuration. When this limit is considered, the worst control configuration permitted by our present Technical Specifications will result in only a 12.0 kw/ft peak. In this case, there is a factor of 1.3 between the calculated maximum kw/ft and the allowed maximum of 15.8 kw/ft.

RESULTS AT 70% POWER

The previous results were based on rod insertion limits at 100% power. A similar calculation was also made at 70% power. In this instance, the maximum insertion allowed under current Technical Specifications limits was D bank at 59 steps and C bank at 189 steps. Since the 100% power results indicated the worst peaking at maximum full length rod insertion, only the corresponding 70% power maximum full length rod insertion cases were considered. The results of these calculations are shown in Table 2.

As expected, the trend in axial offset and kw/ft versus part length insertion is similar to the 100% power case. The peak F_Q^N is indeed higher with the greater full length rod insertion; however, the kw/ft falls off more rapidly than F_Q^N increases. The net result is that the 70% power condition is less limiting than the 100% power condition.

RESULTS AT LESS THAN 70% POWER

Since the H. B. Robinson core is very close to the end of cycle, the excess reactivity is very close to being depleted. Calculations show that at 70% power with control rods inserted at the maximum allowable limits, the core could remain critical only with all soluble boron removed. Therefore, calculations of F_Q^N were not made at power levels less than 70% since criticality could not be maintained even with all soluble boron removed.

EFFECT OF OSCILLATORY XENON

The previous calculations have assumed that the axial xenon distribution was in equilibrium with the axial power distribution just prior to control rod insertion. This condition is not always true, since it is a normal occurrence to have small oscillations in the axial power which produces oscillations in the axial

xenon concentration. The effect of non-equilibrium xenon on control rod insertion limits was considered by examining two cases where the xenon was redistributed either toward the top or bottom of the core prior to control rod insertion.

The magnitude of the xenon redistribution approximated the effect of +20% and a -20% axial power offset. Since the magnitude of the oscillations in xenon concentrations is inversely proportional to the magnitude of the axial power oscillations, the offset in xenon was -20% and +20% respectively for the two cases mentioned above. These conditions approximate a worst case condition because it is extremely unlikely that the reactor operators would ever let the axial offset get larger than ±20% before taking corrective action. A more typical value of axial offset during normal operation is ±5%.

Case A3, which had the largest F_Q^N, was re-examined with the non-equilibrium xenon. The results are shown in Table 3. With the xenon peaked at the top, F_Q^N increases from 2.26 in the equilibrium case to 2.55. The axial offset becomes even more negative, so that a scram would occur before the peaking factor reached 2.55. For xenon peaked at the bottom of the core, F_Q^N is reduced to 1.54. Therefore, it is concluded that the effects of oscillatory xenon will not invalidate the current control rod insertion limits.

CONCLUSIONS:

Results of these analyses demonstrate that during the remaining of Cycle 1 there are no permissible normal configurations of control and part length rods which will result in the nuclear hot channel factor exceeding 2.75 or 15.8 kw/ft at a rated power of 2,200 Mwt. Additionally, it is further shown that control and part length configurations are considerably more restricted by permissible axial offsets than by the minimum rod insertion limits.

As a result of our frequent (at least monthly during operations) in-core power measurement program, and our demonstrated ability to accurately predict these measurements analytically, the results of these analyses assure that Carolina Power & Light can operate the H. B. Robinson Unit No. 2 limiting the peak kw/ft to 15.8 within the present structure of the Technical Specification for the remainder of Cycle 1 operations.

Very truly yours,

E. E. Utley
Vice President
Bulk Power Supply

WMS:jb

CC: Mr. C. D. Barham
Mr. N. B. Bessac
Mr. B. J. Furr
Mr. S. P. Grant

TABLE 1

RESULTS AT 100% POWER

Case	Power (%)	D Bank (Steps)	C Bank (Steps)	PL (Steps)	A.O. (%)	F_Q^N	Kw/ft
A1	100	107	217	225	-35.1	2.05	11.5
A2	100	107	217	167	-55.5	2.21	12.4
A3	100	107	217	110	-44.2	2.26	12.7
A4	100	107	217	81	-37.6	2.22	12.4
A5	100	107	217	52	-24.2	2.06	11.5
A6	100	107	217	0	-19.0	1.76	9.9
B1	100	150	228	225	-25.5	1.84	10.3
B2	100	150	228	167	-34.8	2.00	11.2
B3	100	150	228	110	-35.8	2.06	11.5
B4	100	150	228	81	-28.5	2.01	
B5	100	150	228	52	-18.4	1.84	10.3
B6	100	150	228	0	-18.5	1.58	8.9
C1	100	190	228	225	-13.1	1.65	9.2
C2	100	190	228	167	-24.9	1.83	10.3
C3	100	190	228	110	-23.8	1.87	10.5
C4	100	190	228	81	-19.2	1.78	10.0
C5	100	190	228	52	-05.2	1.61	9.0
C6	100	190	228	0	+01.3	1.49	8.3
D1	100	228	228	225	-05.6	1.46	8.2
D2	100	228	228	167	-14.9	1.68	9.4
D3	100	228	228	110	-09.3	1.65	9.2
D4	100	228	228	81	-00.8	1.57	8.8
D5	100	228	228	52	+01.8	1.66	9.3
D6	100	228	228	0	+11.5	1.71	9.6

TABLE 2

RESULTS AT 70% POWER

Case	Power (%)	D Bank (Steps)	C Bank (Steps)	PL (Steps)	A.O. (%)	F_Q^N	Kw/ft
E1	70	59	189	225	-41.5	2.34	9.2
E2	70	59	189	167	-48.4	2.46	9.6
E3	70	59	189	110	-51.8	2.57	10.1
E4	70	59	189	81	-46.5	2.54	9.9
E5	70	59	189	52	-40.0	2.38	9.3
E6	70	59	189	0	-21.7	2.00	7.8

TABLE 3

EFFECT OF OSCILLATORY XENON

Xenon Distribution	D Bank (Steps)	C Bank (Steps)	PL (Steps)	A.O. (%)	F_Q^N	Kw/ft
Equilibrium	107	217	110	-44.2	2.26	12.7
Peaked at top	107	217	110	-63.5	2.55	14.3
Peaked at bottom	107	217	110	-07.8	1.54	8.6

FIGURE 1

RELATIVE ASSEMBLY POWER

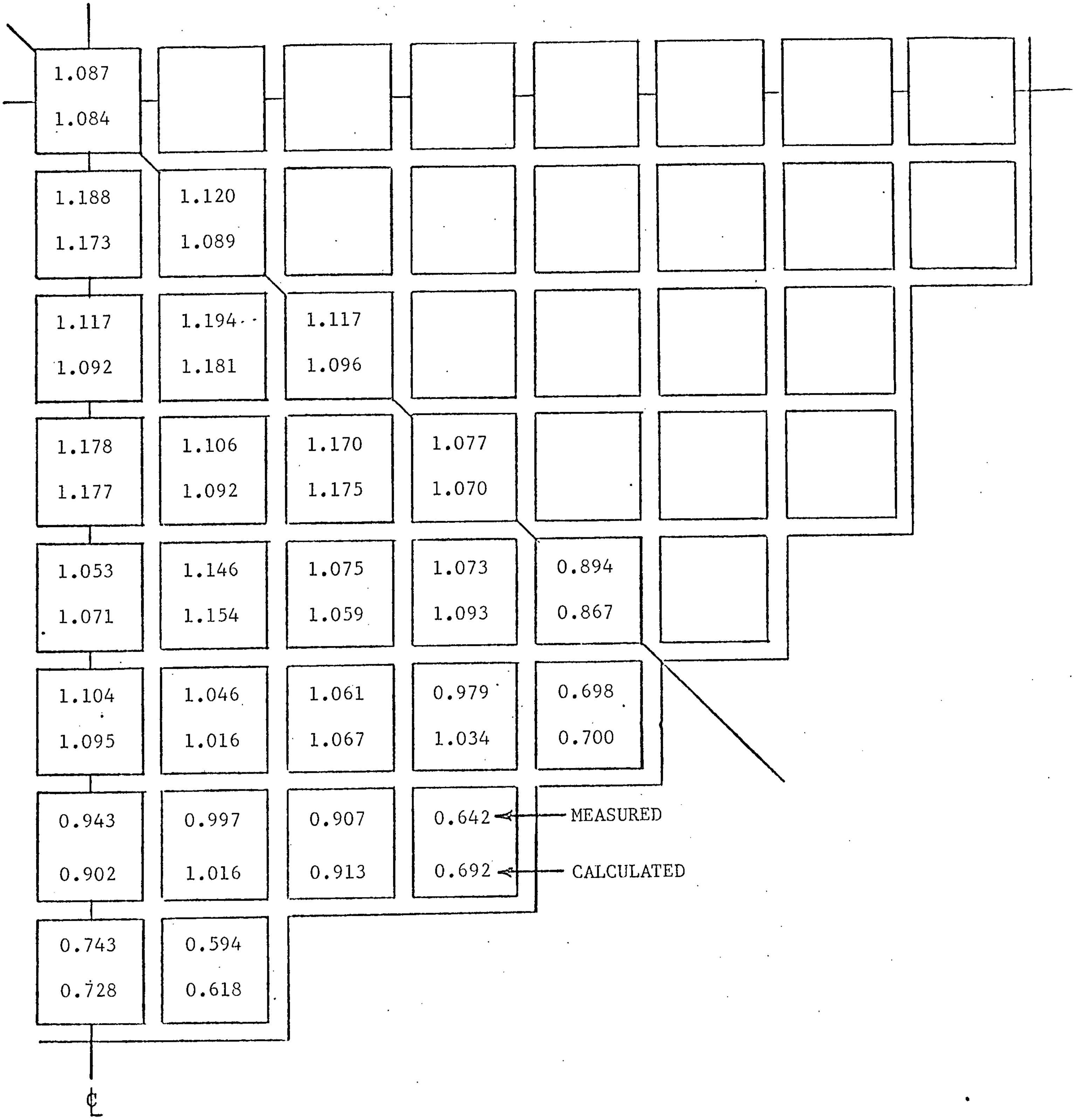
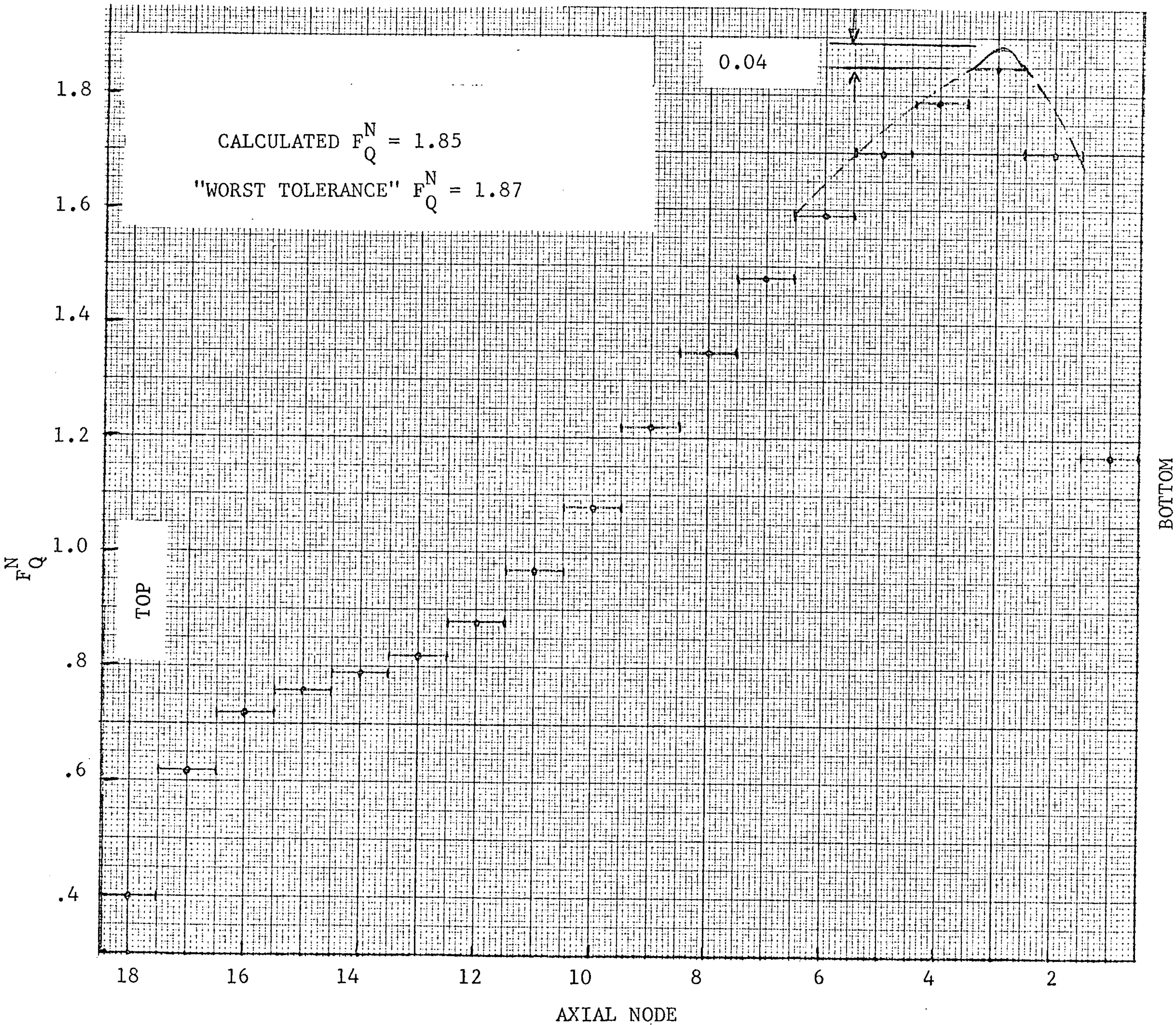


FIGURE 2



CALCULATED F_Q^N = 1.85
"WORST TOLERANCE" F_Q^N = 1.87
0.04
TOP
BOTTOM
F_Q^N
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
18
16
14
12
10
8
6
4
2
AXIAL NODE

FIGURE 3

CONTROL & PART LENGTH ROD BANK LOCATIONS

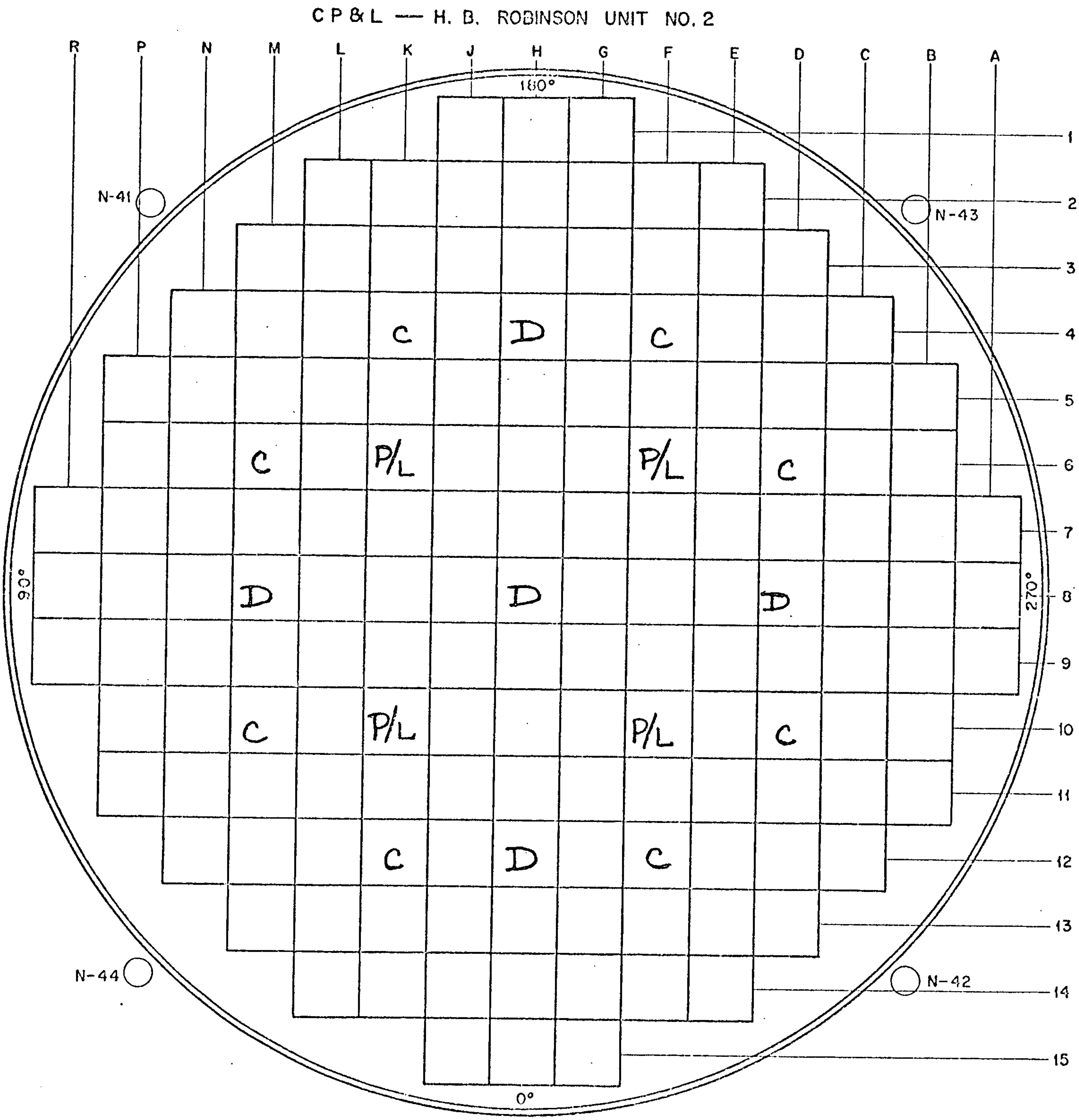


FIGURE 4

CONTROL GROUP INSERTION LIMITS
FOR 3 LOOP OR 2 LOOP OPERATION

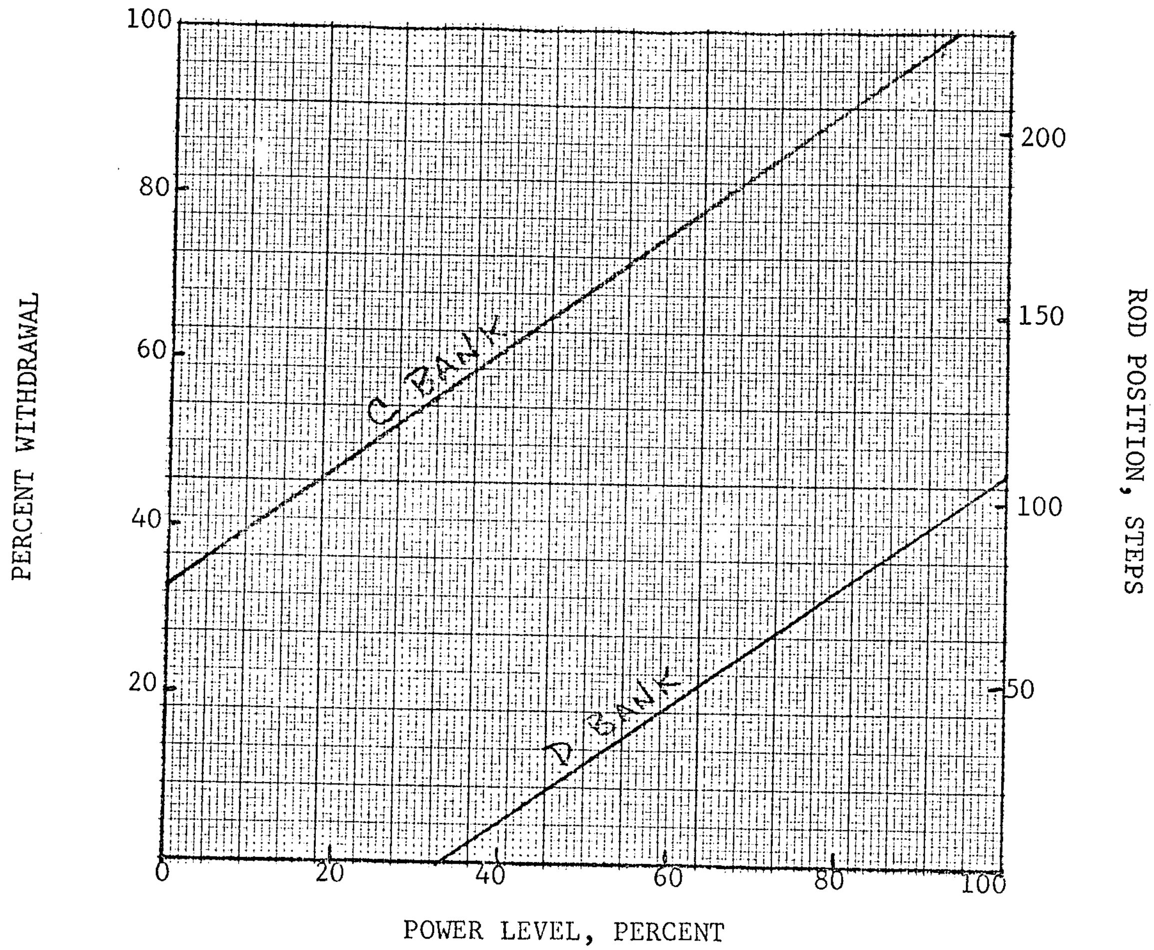


FIGURE 5

CONTROL BANK D POSITION
vs.
P/L BANK POSITION
100% POWER

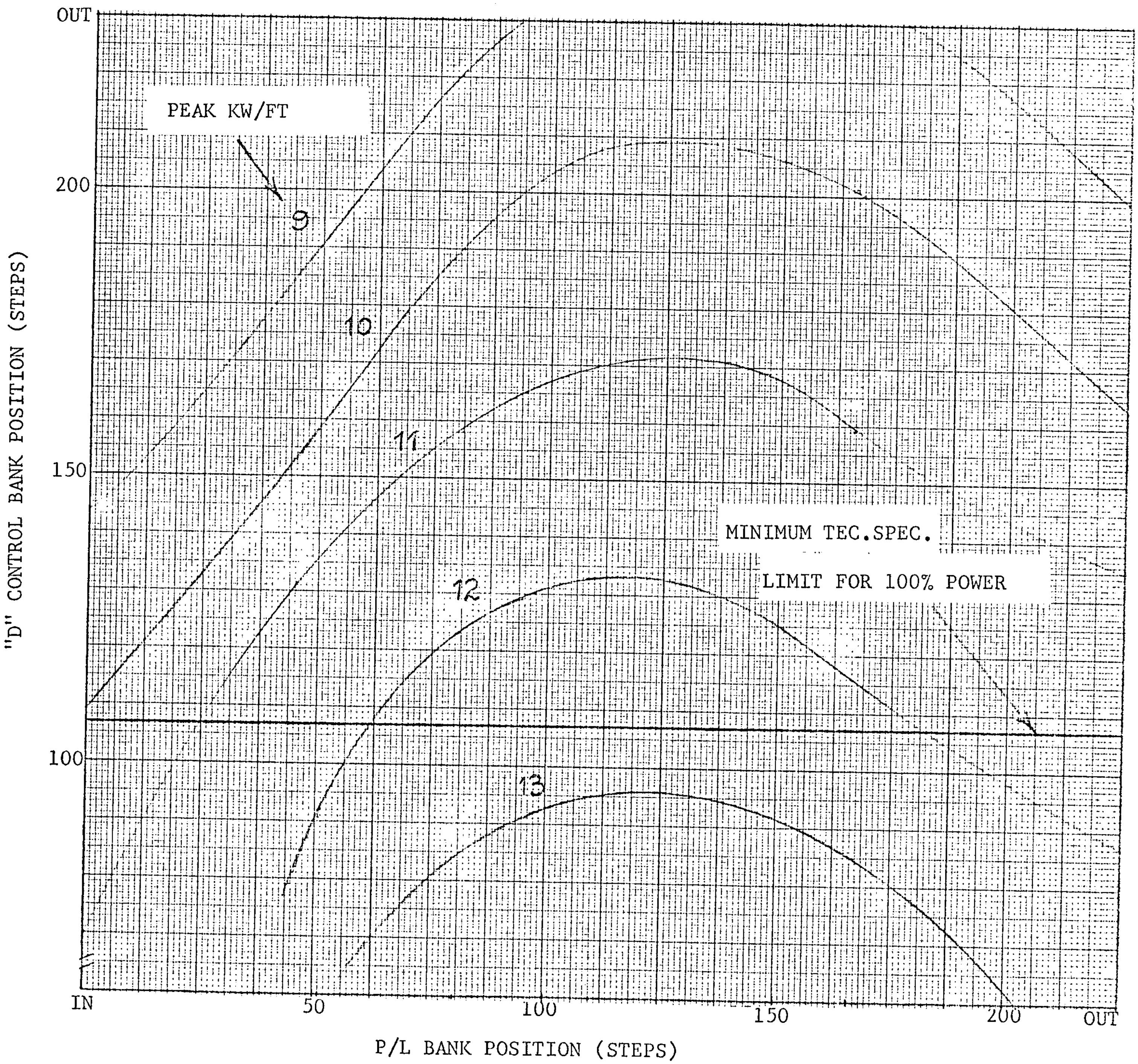


FIGURE 6

CASE A 3

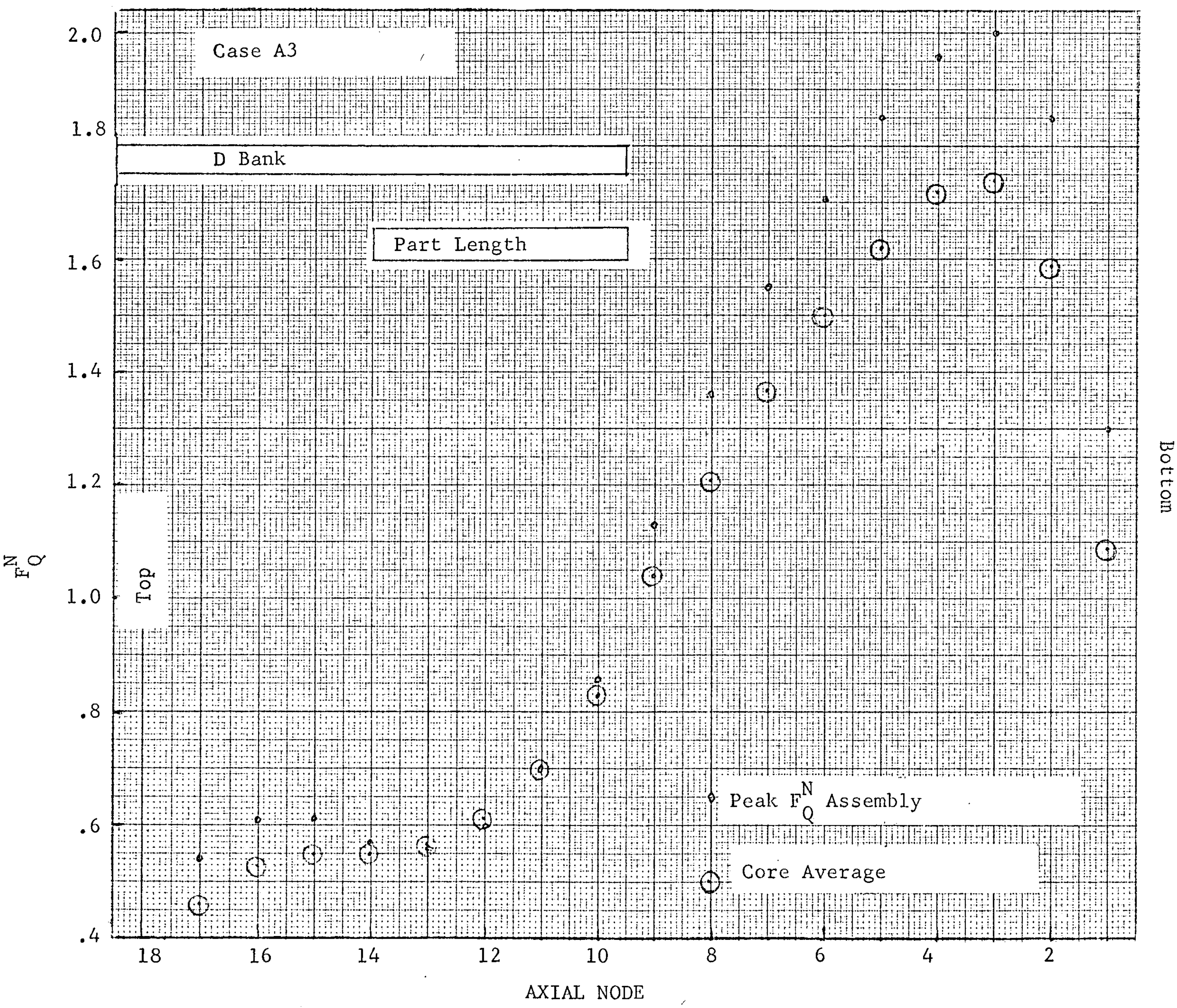


FIGURE 7

CASE B 3

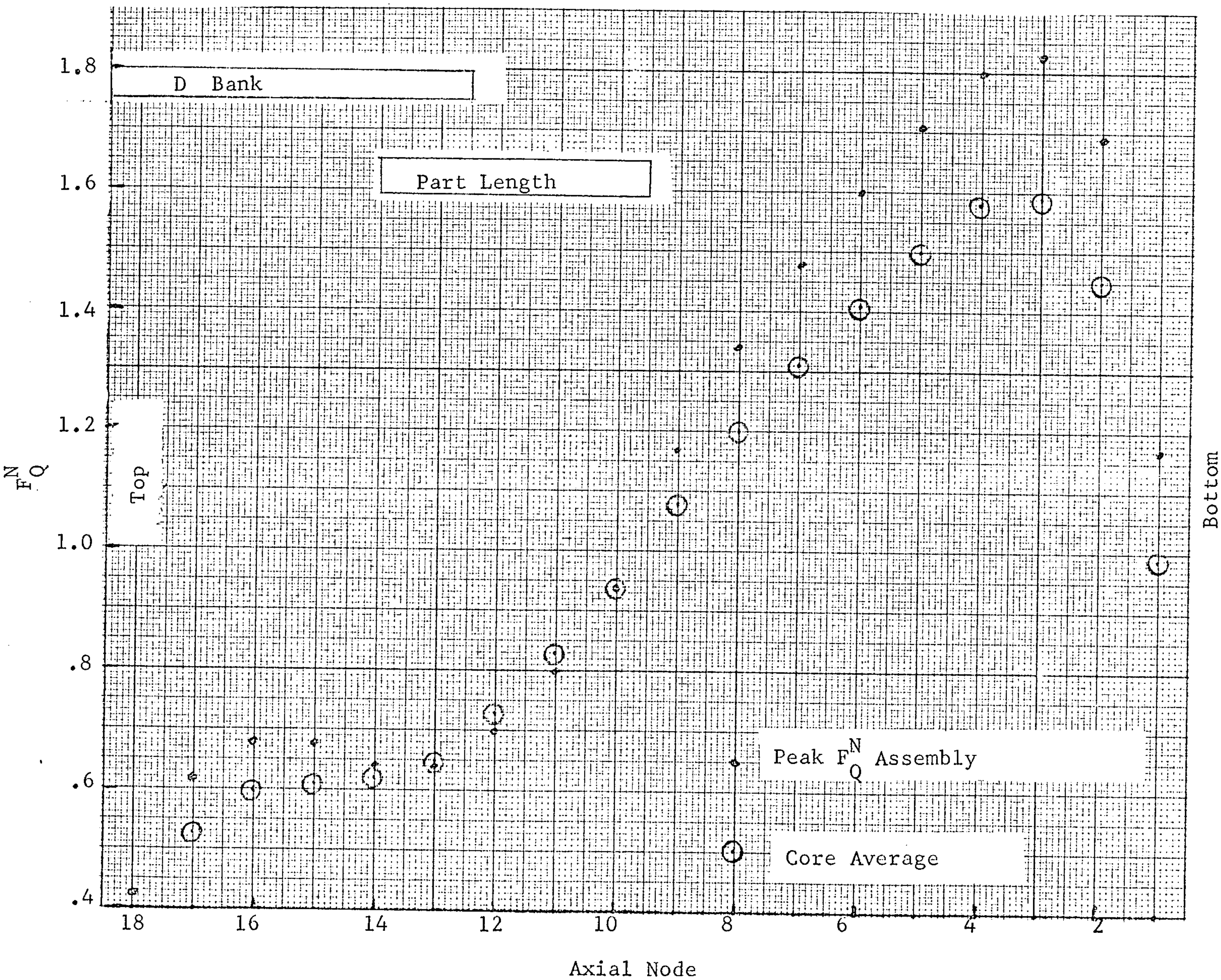


FIGURE 8

CASE C 3

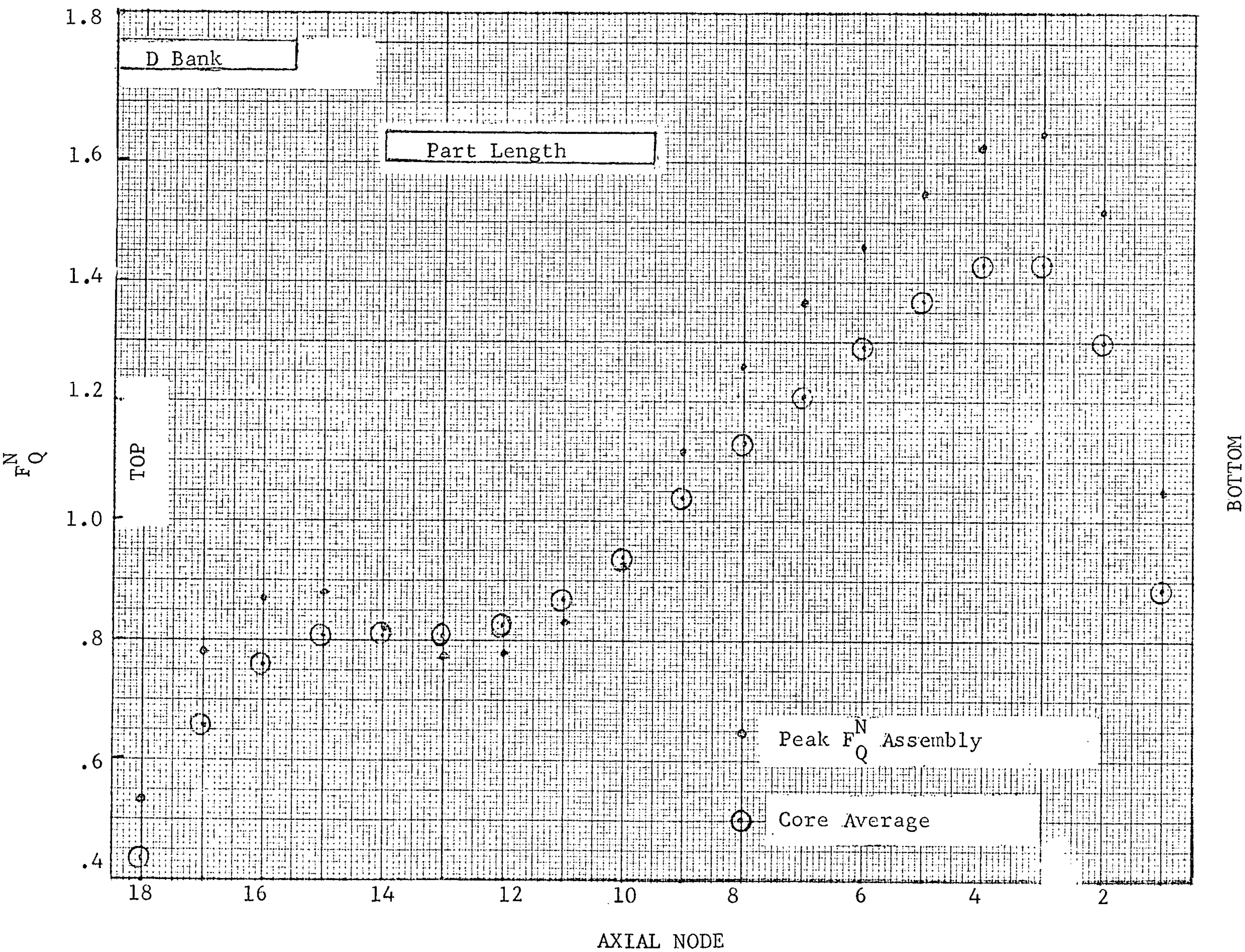


FIGURE 9

CONTROL BANK D POSITION
vs.
P/L BANK POSITION
FOR CONSTANT
AXIAL OFFSET VALUES

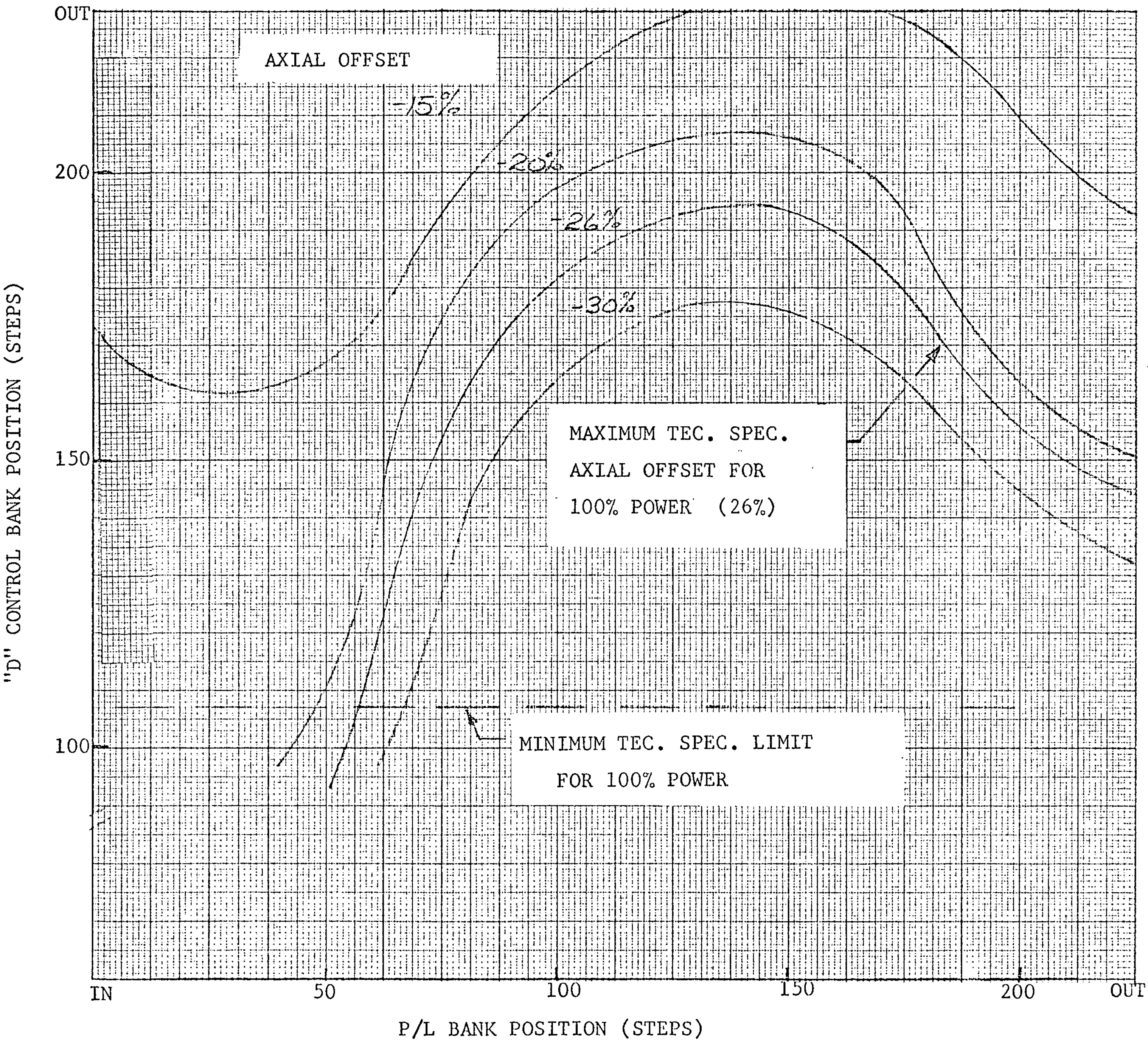


FIGURE 10

CONTROL BANK D POSITION
vs.
P/L BANK POSITION
100% POWER