ATTACHMENT 2

INDEX TEST BOX RESULTS

PHP #2

Woodward Governor Company

1987-12-04 Bauman on PHP2.max

Introduction

In December, 1987, the Index Test Box (ITB) was installed at Portland Hydro Plant #2 (PHP-2), operated by Portland General Electric (PGE). After installation fifty-six sets of data were collected to determine the optimum head-gate-blade relationship for the unit.

The head-gate-blade relationship is the surface, or family of curves, which the electronic 3D cam uses to position the blades. This surface indicates to the 3D cam at what angle the blades should be for a given net head and gate position. The optimum relationship is the surface which will allow the blades to be positioned so that the turbine will be running at its maximum efficiency.

The ITB is an efficiency optimizer for adjustable blade type turbines. Using input signals of headwater, tailwater, gate position, blade angle, flow, and power output of the unit, the ITB can determine the optimum operating gate to blade relationship for a given head and load setpoint. Presently there are two prerequisites to using the ITB. They are:

(1) The unit must have load, or generation, feedback, and
(2) A Woodward Mod 2 electronic 3D cam must be used to position the blades.

Initially, PHP-2 used a mechanical 2D cam to position the blades. This was removed, and a 3D cam was put in its place.

Data Collection

Basic index testing in the hydro industry has traditionally been one of the following two forms:

(1) Fixed blade, moving gate and generation.
(2) Fixed gate, moving blade and generation.

The first method is preferred, due to the gates being easier to position manually and the gate to generation, and thus the gate to efficiency, resolution being higher.

The ITB, however, performs a constant generation, moving gate and blade test. This type of test must be performed with a load feedback governor. The ITB is responsible for positioning the blades, while the governor compensates by adjusting the gates to hold the unit generation constant. One advantage of this is that the data occurs along the generation lines, making plotting and evaluating the efficiency map more straight forward. Another advantage is that there is less power swing during a test, making it nearly transparent to the operator.

The ITB, in order to perform this test, goes through a number of steps in order to insure that the data collected from a unit is valid. The steps are as follows:

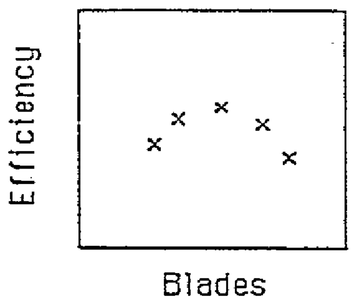
(1) The unit collects a number of measurements from each of the input channels. The actual number of measurements is determined during ITB calibration. Each group of these measurements is then averaged, and a standard deviation for each is determined. If all of the standard deviations are within a specified range, as determined during calibration, the unit is determined to be free from noise, and the averages are saved as samples. If one of the standard deviations is out of range, the entire set is discarded and the measurements are retaken. If the measurements continue to have standard deviations which are out of range, the testing is halted and a message appears on a screen indicating that the unit is running too roughly.

(2) A number of samples, as explained above, is collected from each of the input channels. The actual number of samples is determined during unit calibration. Once the specified number of samples is collected, these are averaged, and a standard deviation is determined for each input. If all of the standard deviations fall within the desired range, the unit is determined to be steady-state (not in a transient condition), and the averages are saved as a data point. This is the actual data which is saved at the operating point. If one of the standard deviations fails to meet the specified range, the entire set of samples is discarded and the testing at that point is restarted.

(3) Once a data point has been determined, the ITB begins its blade slewing process. The criterion for a complete test is: locate a point with an efficiency higher than that of the two points on either side. This can be seen in figure 1 below. The blades are either incremented or decremented by an angle specified in calibration, and another data point is collected. Once the above criterion is met, the data from the completed test is stored on a UV-erasable PROM.

Two of these EPROM chips were returned by PGE to Woodward for data reduction and forming new cam curves.

Figure 1:



Data Reduction

After the data was back at Woodward, it was pulled off the chips and put through a series of steps in order to determine the optimum head-gate-blade relationship for the unit.

First, the data was manually checked to be sure that all data to be used in determining the new cam surface was valid. This resulted in discarding all but 34 of the tests. A number of the tests showed that the load setpoint of the unit had been changed during the course of the tests, rendering the data invalid. A number of others were incomplete (they did not contain a maximum efficiency point with two less efficient points on either side), and were likewise discarded.

Next, the remaining data was loaded into a cubic spline program to determine the maximum gate-blade relationship for a given head and load. A cubic spline is a curve which passes through every data point. The slope on either side of a point is equal, so the curve is continuous. Graph 1 shows efficiency vs. blade curves for each of the sets of data. For each of these curves, the (peak efficiency, blade) pairs were retained to be used in the next calculation.

The same data also was run through the same cubic spline program to determine the blade vs. gate curves for each of the tests. This is shown on Graph 2. The above peak blade points were used to mark the peak efficiency blade-gate points on these curves. Data retrieved by the ITB also indicated the on-cam positions for the tests, and these were also put on this graph.

Graph 3 shows the peak and on-cam points for each of the blade-gate pairs. The curves were removed for clarity.

Next, each of the peak efficiency and on-cam ordered pairs was put into another program. This program was used to determine a 3rd order least squares formula for each of the curves. A least squares curve may not pass through every data point, but it will minimize the total error of points which do not lie on the curve. Graph 4 shows the results of this.

After this, the data from the manual index test performed by the Bonneville Power Administration (BPA) and PGE was loaded into this program. The on-cam and new maximum efficiency curves from the manual index test are shown along with the curves generated by the index test box of Graph 5.

In the BPA report, it was shown that there is a some variance in the input signals between the ITB signals and those from the index test. Linear regression formulas for the gate and blade signals were provided, and the ITB data was corrected to these equations. Graph 6 shows the results of these corrections on the data. The BPA indicated that no head correction was made on the on-cam data. From this graph, it can be observed that the two on-cam curves are basically coincident. This implies that both tests were done at an identical head.

But the two maximum efficiency curves do not seem to agree at all. It appears that the ITB maximum efficiency curve is much flatter than that of the manual index test. This is because the BPA data was corrected to a common head, while the ITB data was not. At larger gate positions, the unit flow is greater, and therefore the velocity head loss of the unit is greater. At the unit's maximum flow, the ITB was measuring a head

$$H_m + \frac{V^2}{2g} = H_a \quad \text{: Neglecting friction losses}$$

H_m = Head measured by ITB
H_a = Actual static head
V = velocity of water in penstock
g = gravitational constant

Other values:

Maximum flow rate = 2000 cfs
Penstock diameter = 10.5 feet

$$V = \frac{Q}{A} = \frac{2000}{\pi\left(\frac{10.5}{2}\right)^2} = 23.1 \text{ ft/s}$$

$$\text{Velocity head loss} = \frac{V^2}{2g} = \frac{23.1^2}{2 * 32.2}$$
$$= 8.3 \text{ feet}$$

less than at no flow. This is the cause for the difference.

Next, the ITB on-cam curve was placed back on the model curves to determine the actual new cam curves. The reason for this is the present on-cam curve was made using the model data. Using the model data, it could be observed how the velocity head loss was affecting the curves. Making a correction for the velocity head loss, a new peak efficiency curve for a constant net head was generated. This is shown in Graph 7.

Finally, all of the curves were corrected by the change between the on-cam and maximum efficiency lines to generate a new head-gate-blade surface. This is shown in Graph 8.

It should be noted that data was not collected from the unit at below 40% gate. The ITB does not work well in this area, because decrementing the blades will cause them to encounter the flat position before the test is completed.

Conclusion

It can be seen in comparing the BPA and the corrected ITB maximum efficiency curves, they are almost identical. This shows that the ITB is effective in determining the maximum efficiency operation of an adjustable blade hydro unit.

With the manual index test, a very crucial step in the evaluation process is determining the tangent time of the blade-power curves. This can only be done manually. A different person examining the same data may have come up with a slightly different result. The index test box allowed us to avoid this step.

One purpose of the ITB is to automate, as much as possible, the process of generating new cam curves for an adjustable blade type unit. Although much of the ITB process was performed by computers, there was still a human element required in producing a final result.

Examples of this can be seen in the data reduction phase. The elimination of tests was done by hand, along with correcting the maximum efficiency data to a common nethead using the model cam data. These operations may have been possible using a computer, but experience and insight were far more reliable in the final determination.

The relative ease of use of the ITB, combined with the ability to perform tests at any desired time, make the ITB a convenient optimizer for adjustable blade turbines. The manpower requirements are minimal which makes the testing very cost effective..

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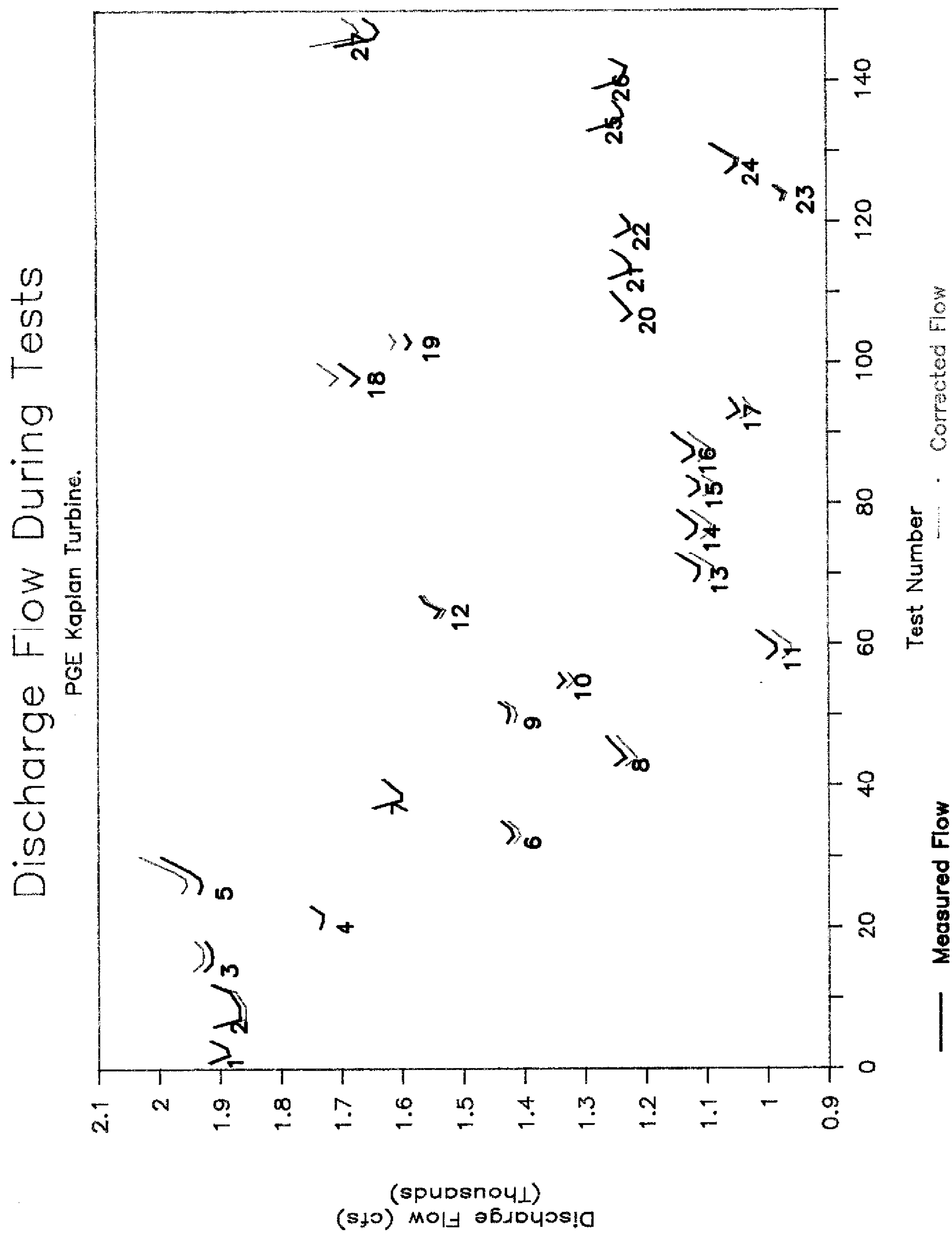
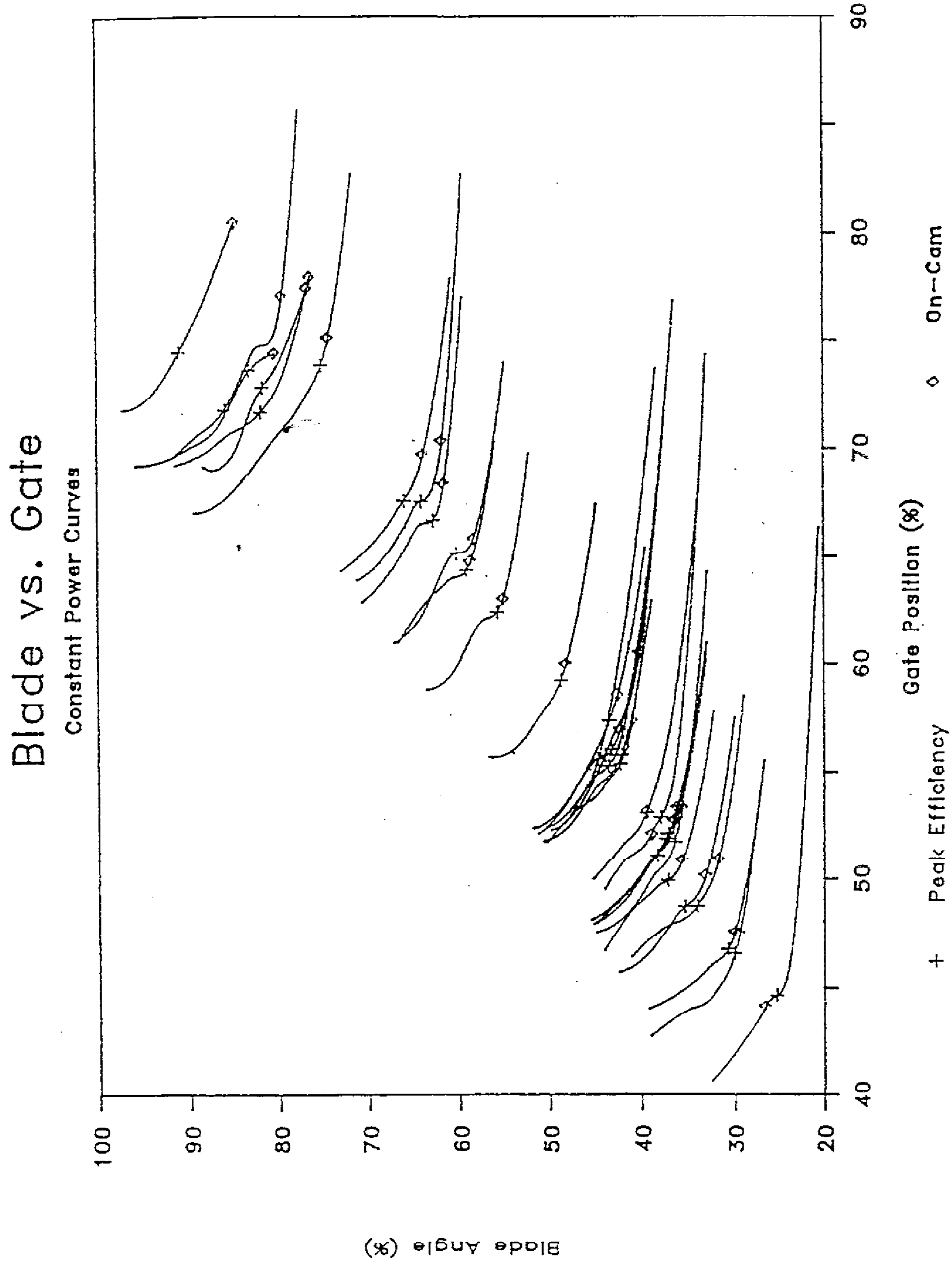

Discharge Flow During Tests
PGE Kaplan Turbine.
Discharge Flow (cfs)
(Thousands)
Test Number
Measured Flow
Corrected Flow
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0
20
40
60
80
100
120
140



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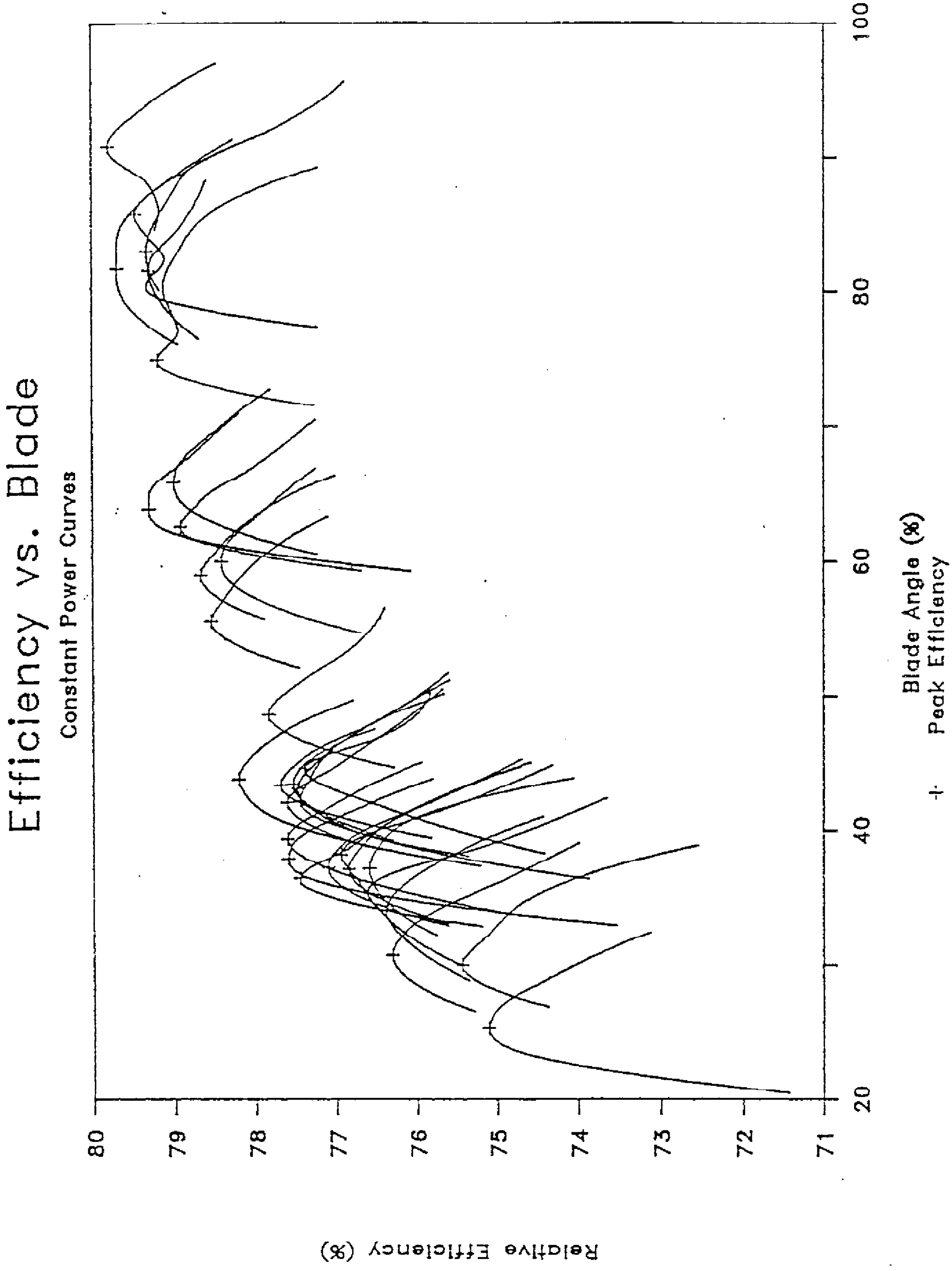

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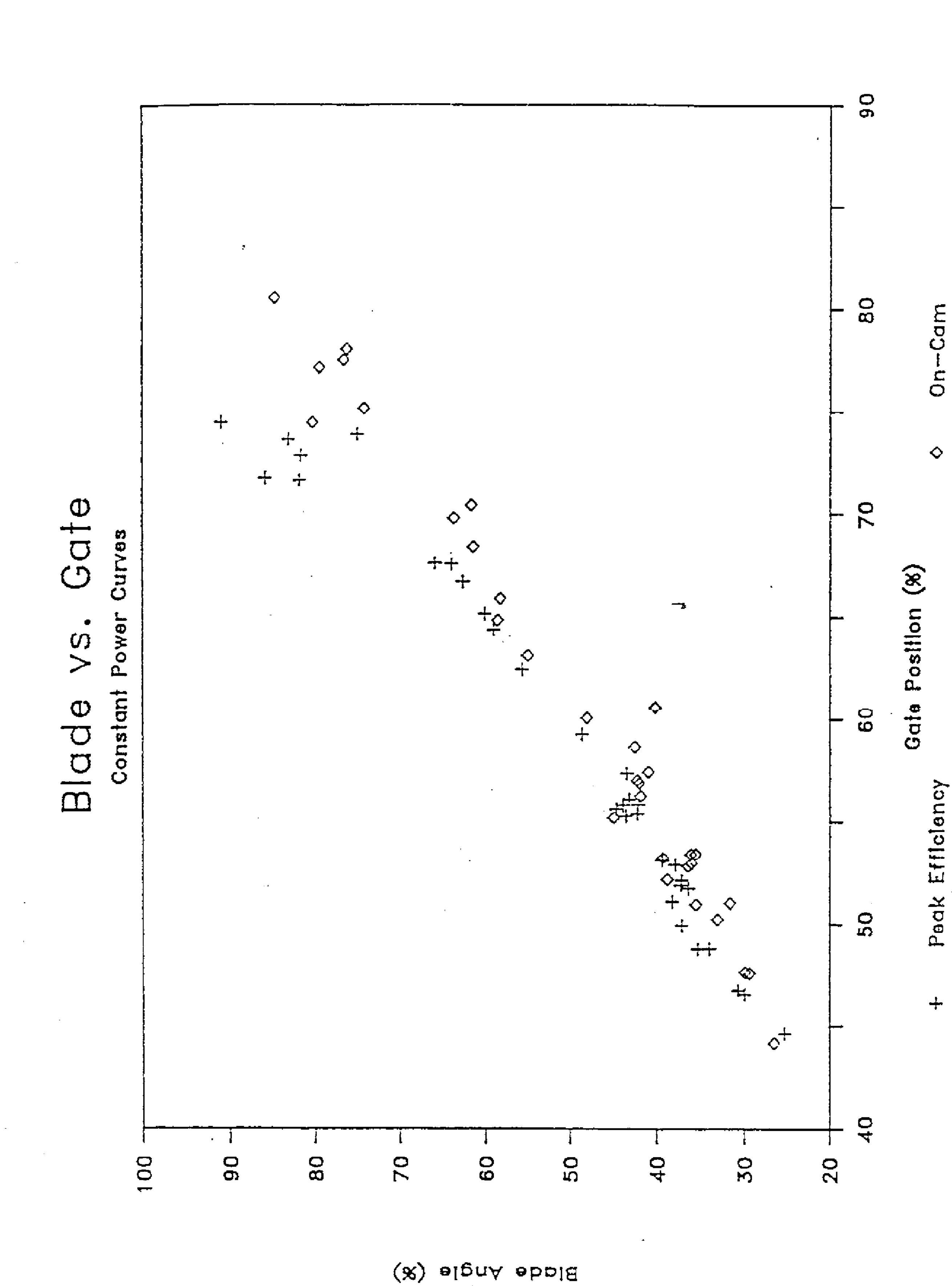

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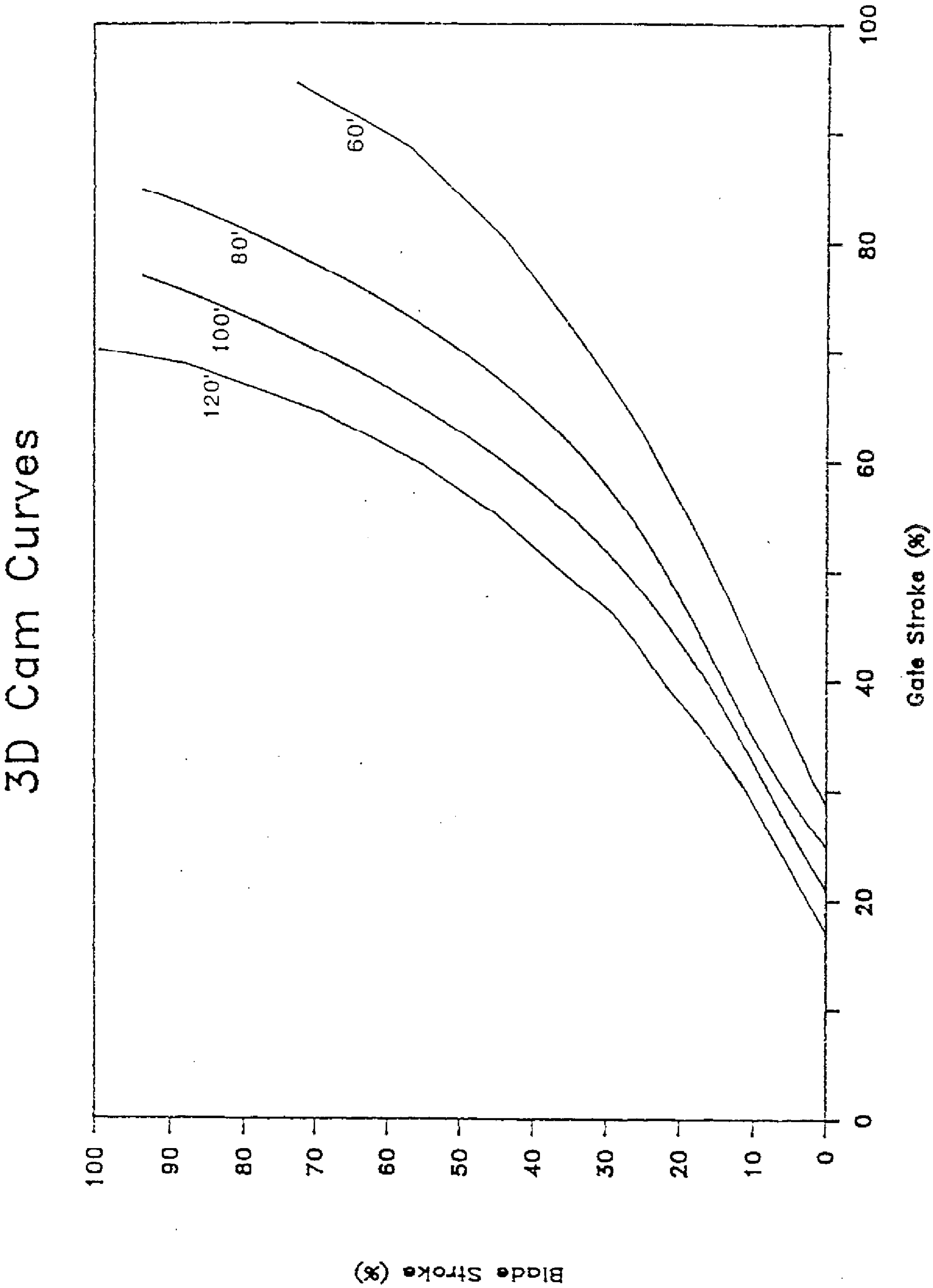
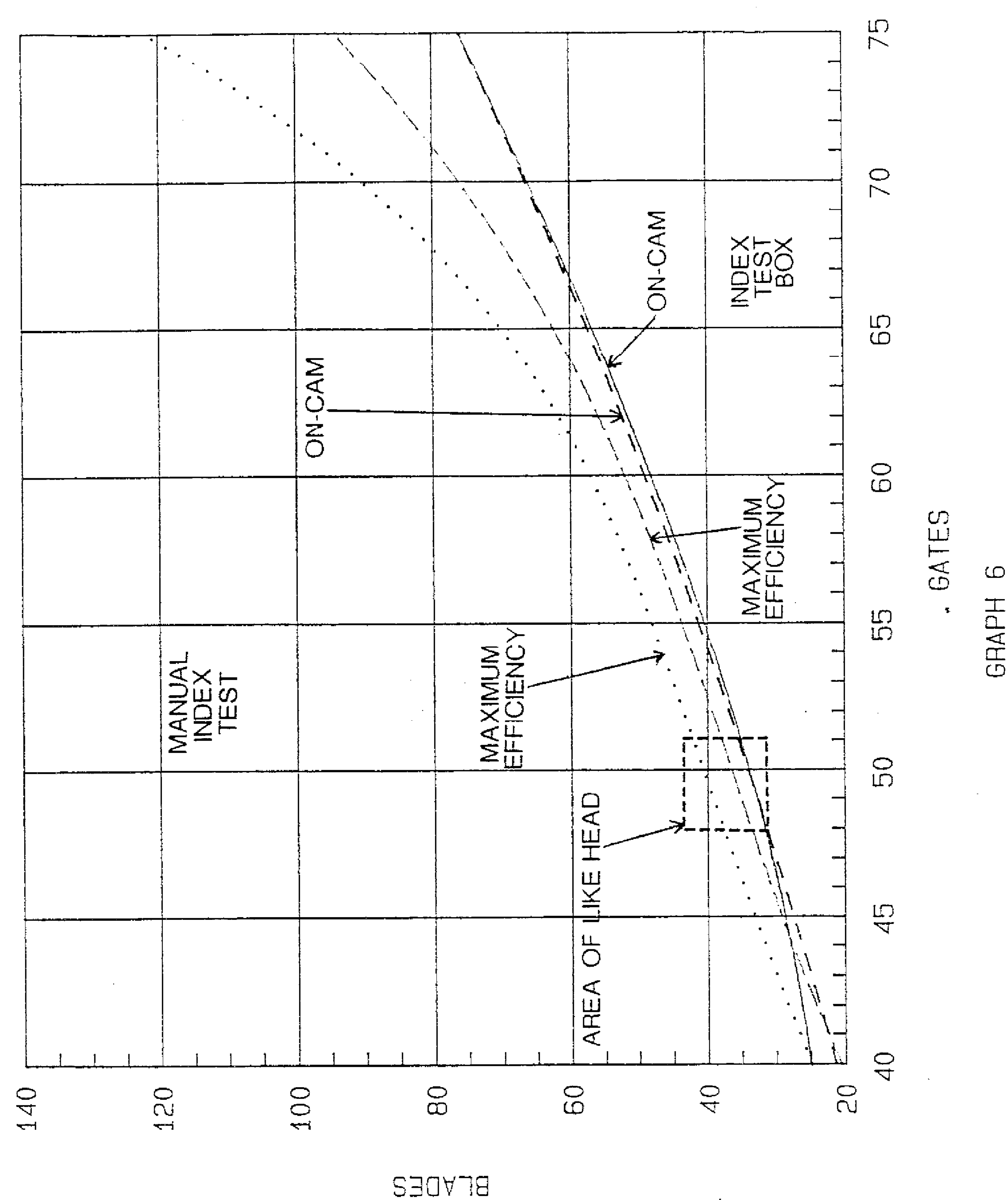
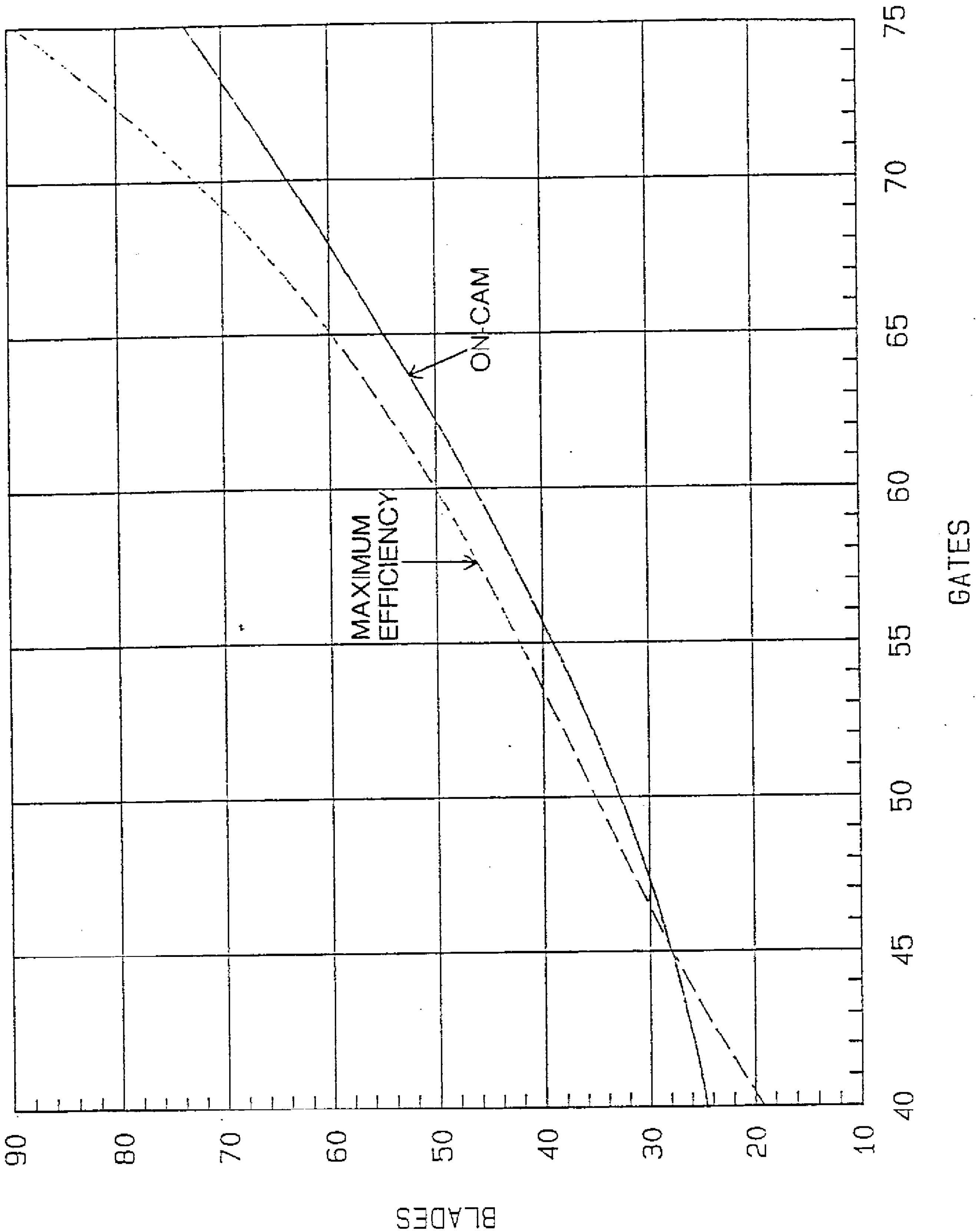

3D Cam Curves
Gate Stroke (%)
Blade Stroke (%)
60'
80'
100'
120'
0
20
40
60
80
100
0
10
20
30
40
50
60
70
80
90
100

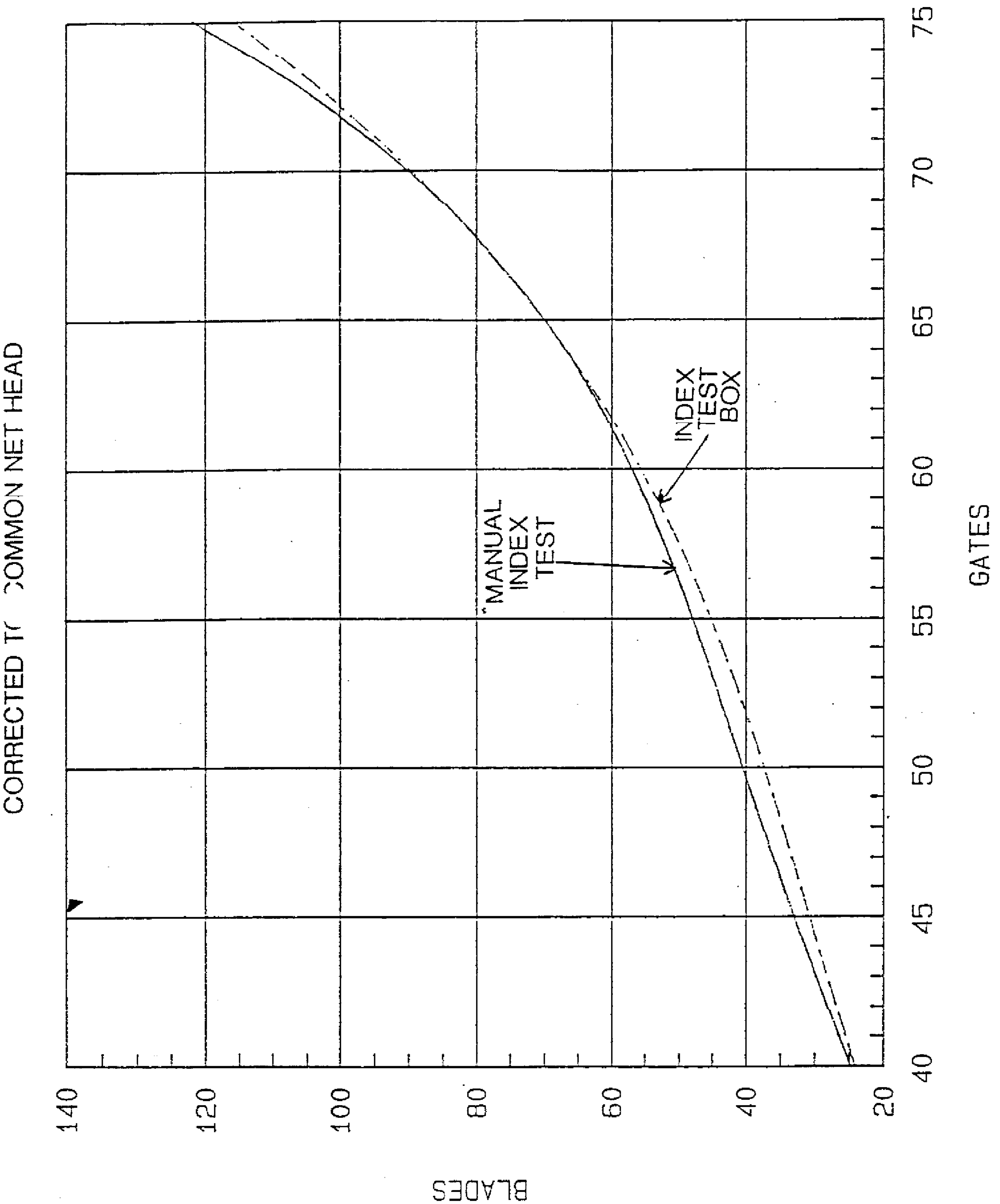


MANUAL INDEX TEST
ON-CAM
ON-CAM
INDEX TEST BOX
MAXIMUM EFFICIENCY
MAXIMUM EFFICIENCY
AREA OF LIKE HEAD
GATES
BLADES
140
120
100
80
60
40
20
40
45
50
55
60
65
70
75

GRAPH 6


ON-CAM
MAXIMUM
EFFICIENCY
GATES
40
45
50
55
60
65
70
75
BLADES
10
20
30
40
50
60
70
80
90

GRAPH 4


CORRECTED T
OMMON NET HEAD
MANUAL INDEX TEST
INDEX TEST BOX
GATES
BLADES
40
45
50
55
60
65
70
75
140
120
100
80
60
40
20

GRAPH 7