Department of Energy

Bonneville Power Administration
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In reply refer to: RMGB

Mr. Tom Thorsen
Project Operations
Portland District
U.S. Army Corps of Engineers
P.O. Box 2946
Portland, OR 97208

Dear Mr. Thorsen:

We wish to thank you for the opportunity to review the relative efficiency test data that your automated index test device recorded on unit #18 at Bonneville second powerhouse. Your recently developed test device, which virtually eliminates the labor intensive nature of these field tests, should find wide application in improving the efficiencies of existing hydroelectric generating units.

Our analysis of this data, all for a test head of 60 ft, disclosed several interesting features. First, there is a very pronounced and unusual hydraulic disturbance within this turbine. This type of disturbance causes considerable difficulty in reducing index or relative efficiency test data. However, the exact shape of the optimum efficiency curve could be derived and it shows that the maximum generating efficiency occurs at about 65.5 MW. Another data plot shows this is certainly a double regulated Kaplan turbine. That is both gates and blades separately affect the flow rate. In other words, for the same head and gate opening, a steeper blade angle causes a higher discharge as well as the familiar wider gate opening causing a higher discharge at constant head and blade angle.

Two different methods of deriving the optimum blade-to-gate cam curve were developed, including a unique three dimensional plotting technique. This latter, considered easier to use and the more accurate of the two, shows a blade-to-gate cam curve, which as a check point at 65.0 percent gate opening shows an optimum blade angle of 20.8°.

Now looking at these features in more detail, it was observed at the site that the Winter-Kennedy (W-K) piezometers are hydraulically very "noisy"; that is, they exhibit a large and rapid oscillation. It is of particular interest, not that there is an oscillation, but that these oscillations are asynchronous or 180° out of phase. All of the Winter-Kennedy's we have observed to date have had synchronous oscillations such that as one piezometer rose or fell, the other rose or fell correspondingly. This occurs due to the pressure pulsations being uniform across the radial cross section of the semi-sprial case. On unit 18, however, this asynchronous oscillation may be symptomatic of a hydraulic disturbance in the waterpassage which effects only one piezometer. As that piezometric water surface rises or falls it compresses or rarefies the common air column causing the other piezometric water surface to move exactly the opposite. It is noted that the Winter-Kennedy piezometers at this powerhouse were not installed according to code. That is, instead of the inner and outer piezometers being in a radial plane from the center of rotation there is about a six foot offset between them. The effect of this is unknown.

The first attempt to reduce this test data was done in the conventional manner. First, the Affinity Laws were used to convert the generator output and square root of the W-K's test data to the equivalent values at 60 ft. of head. Then both were plotted against wicket gate servomotor stroke as shown on LOTUS graphs 1 and 2 to form the standard "smooth curves". Since for this method of field testing no machine parameters are held constant, these graphs simply show the operating envelopes over which the large number of data points were recorded. However, there is a unique technique that may be applied when such large volumes of randomly recorded data are available. Eliminating the gate stroke parameter, the generator output was plotted versus the square root of the W-K's on LOTUS graph 3. Not only is the data scatter reduced, but the right hand edge of this data group is clearly delineated. This is important because this edge is the line of optimum relative efficiency. That is, it is the line where the most power is obtained for a given flow or conversely the least flow is required for a given power. Computing the values of relative efficiency at various points, this line is replotted on graph 4 and reveals several factors. First, maximum generating efficiency occurs at about 65.5 MW. Second, this efficiency curve is actually quite flat. Efficiencies between about 55 MW and almost 74 MW are within 1 percent of the maximum possible efficiency. Thirdly, it might be informative to convert the horizontal axis into turbine horsepower by accounting for the generator losses and then comparing the SHAPE of this curve with that from the model test. Any difference in the shape would be indicative of a nonhomogeneity between the model and the prototype.

Next, the test data was plotted sequentially or in the order it was recorded on graph 5. This shows the double regulated, if not the double hydraulic throttling, nature of the machine. As the brown line for gate opening is increasing for a constant magenta line for blade angle and constant blue line for head, the purple line for the W-K's is, of course, increasing. However, for those points of constant gate opening, as the blade angle increases and the head remains constant, the W-K's also increase. This shows that both the gates and blades independently exert a hydraulic control or throttling of the flow.

The last data evaluation was to determine the optimum blade-to-gate relation to maximize efficiency. The first method attempted was to do a LOTUS sort by increasing gate opening. Then, the data was divided into succeeding groups of 20 data points each. Because of the volume of data the gate opening within each group was virtually constant. Next, the blade angle corresponding to the point of peak efficiency in each group of 20 data points was plotted versus gate opening as shown on graph 6. A least squares linear fit was computed and added to the graph as the optimum blade-to-gate cam curve. This data still has too much scatter and the scatter band width of about 2° of blade angle is too wide to determine any true curvature of the optimum blade-to-gate cam curve.

The next method attempted was to return to the maximum efficiency curve of graph 4 and identify those individual data points which are on or near the curve of maximum efficiency. It was reasoned that the blade-to-gate values from those particular points might define the optimum cam curve. Unfortunately, there was still too much scatter for these data points to accurately define the optimum cam curve.

It was realized at this point, that without any machine parameters being held constant and with the scatter in the data, that a new technique which integrates or averages the individual data points needed to be developed. Fortuitously, it was learned that BPA uses a special computer program which could be adapted to this exact task. Called ESP for "Engineering Site Package," this program is used to develop three dimensional, topographical maps of substation sites from individual benchmark data points. For this present purpose, after inputing all the gate opening data as longitude, blade angle data as latitude, and relative efficiencies as elevations, ESP formed a three dimensional topographical "hill" and then on its surface drew constant relative efficiency contours. A top or plan view of these constant efficiency contours is shown on graph 7. A curve fitting feature of this program then constructed the heavier line forming the "ridge" or the line of peak efficiency. This, of course, is then the optimum blade-to-gate or cam curve. The entire procedure was done in less than one hour. Initially appearing to be busy or confusing, this graph actually provides a clear picture of this unit's performance. From the lower right corner area, larger gates-flater blades, the efficiency rises gradually to the ridge of peak efficiencies. If the blades had a constant position error of 2° in this direction, the absolute efficiency would be 1 1/2-2 percent less. Continuing to move to the upper left corner area, smaller gates-steeper blades, the efficiencies decrease or fall off much more steeply. If the blades had a constant position error of 2° in this direction, the absolute efficiency would be 3-3 1/2 percent less.

It might be informative to plot the cam curve from the model test on graph 7 to evaluate the efficiency improvement your field tests and equipment have obtained for this generating unit.

BPA's ESP computer program is available to your organization and we can reduce any such similar, or even much larger, set of field data your equipment may record. If we can be of further assistance, please let us know.

Sincerely yours,

Lee H. Sheldon

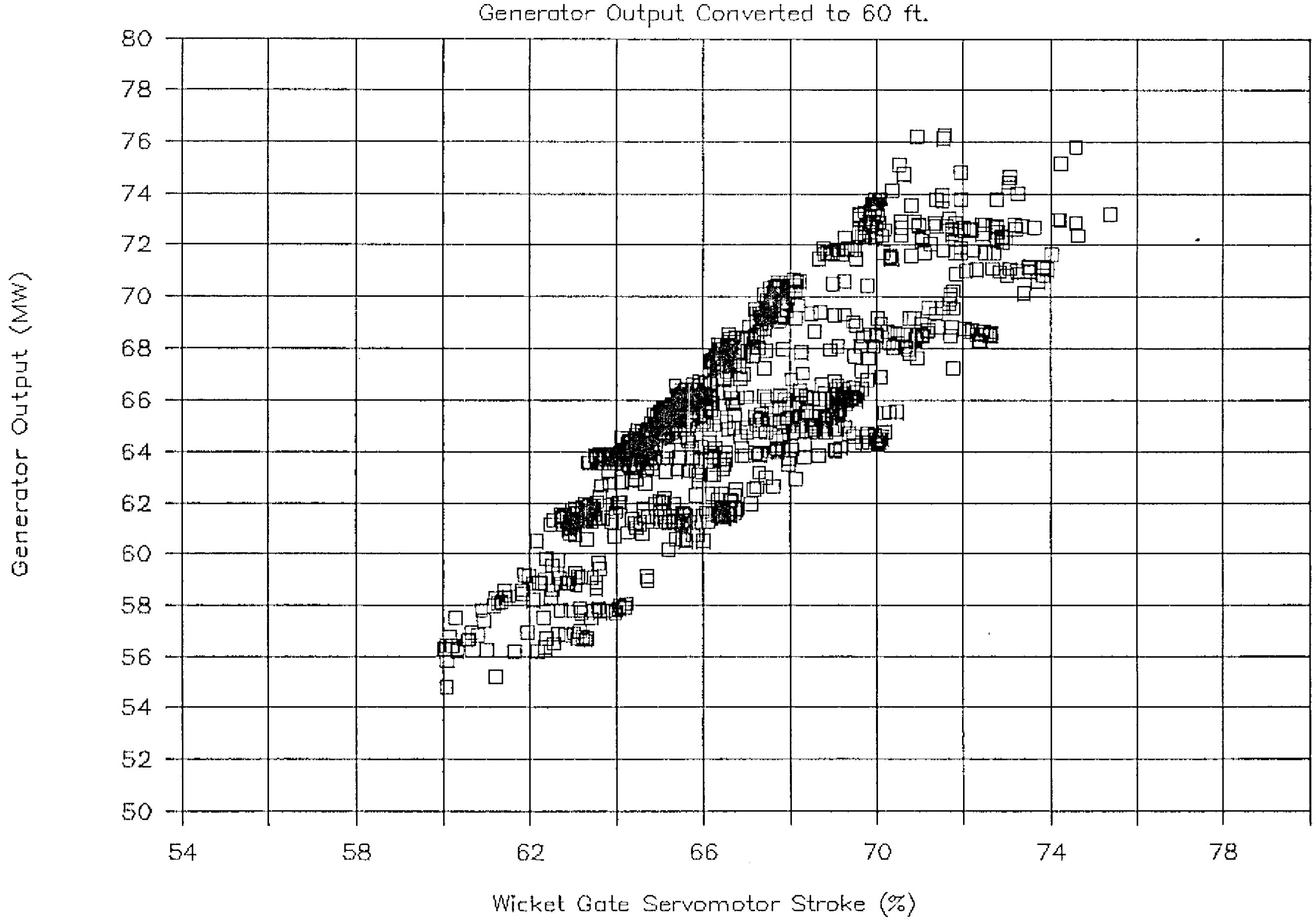
Lee H. Sheldon, P.E.
Senior Hydropower Engineer

Enclosures

cc:
Al Lewey, HDC, Corps of Engineers

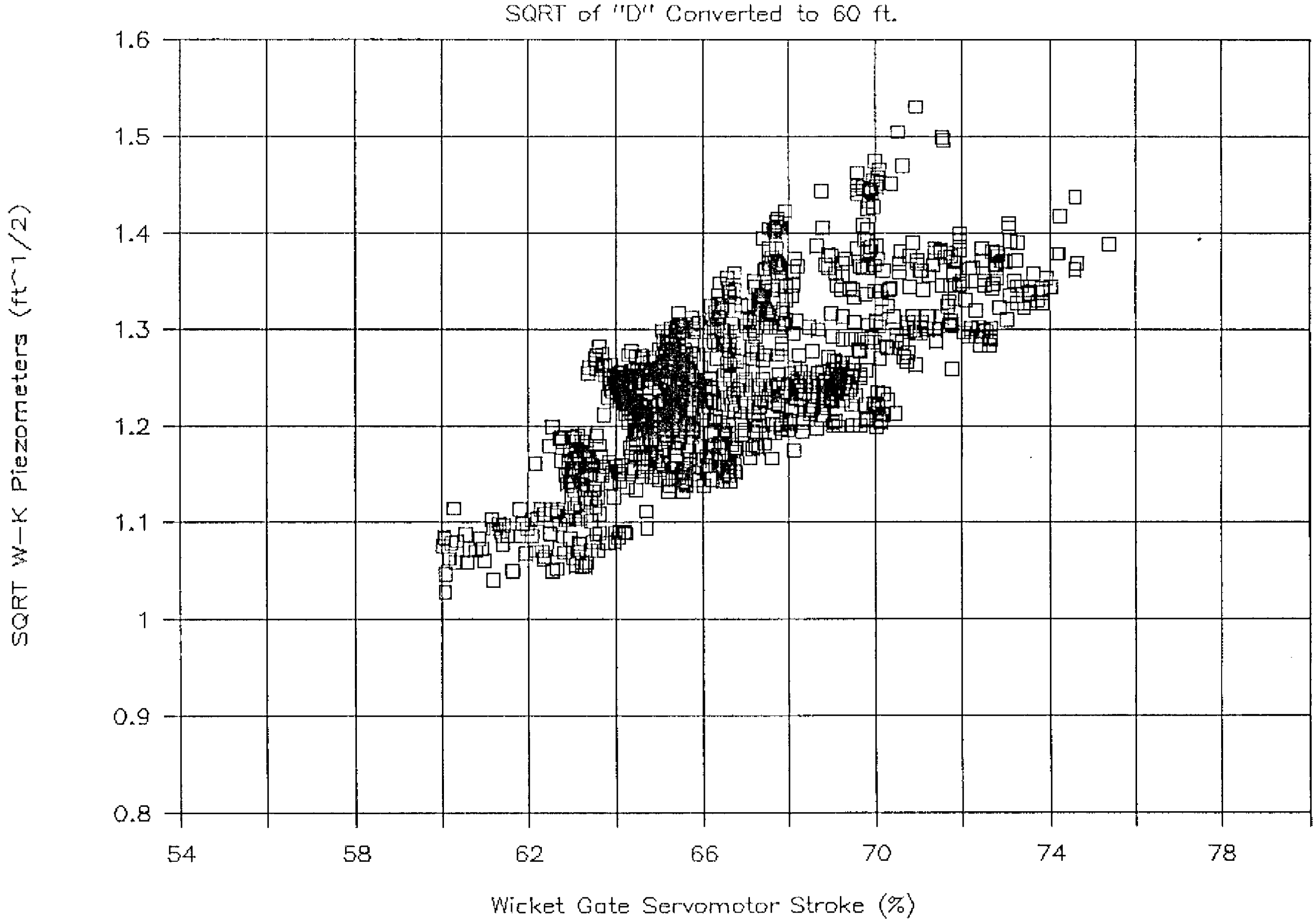
POWER VERSUS GATE STROKE

Generator Output Converted to 60 ft.

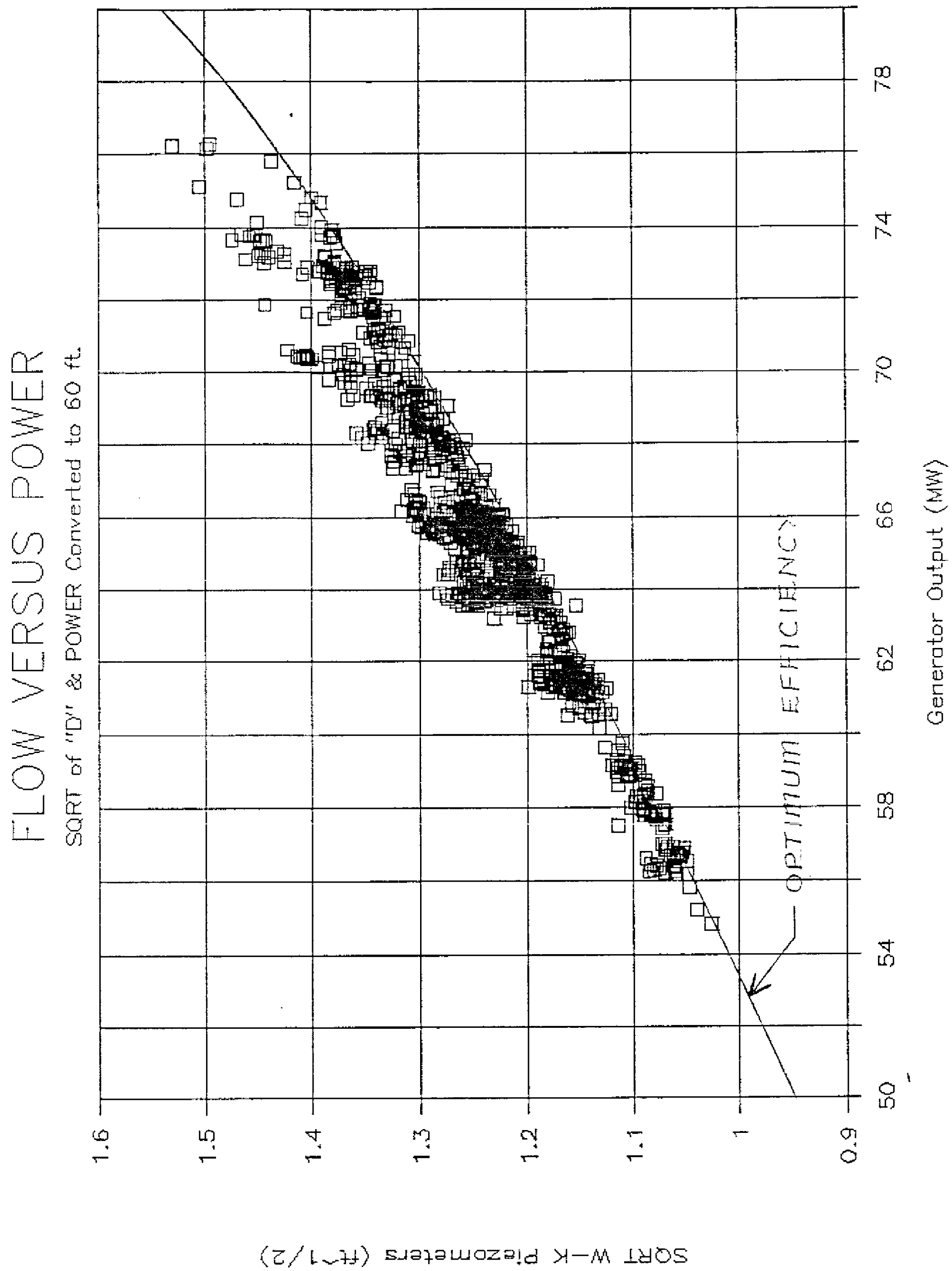


FLOW VERSUS GATE STROKE

SQRT of "D" Converted to 60 ft.

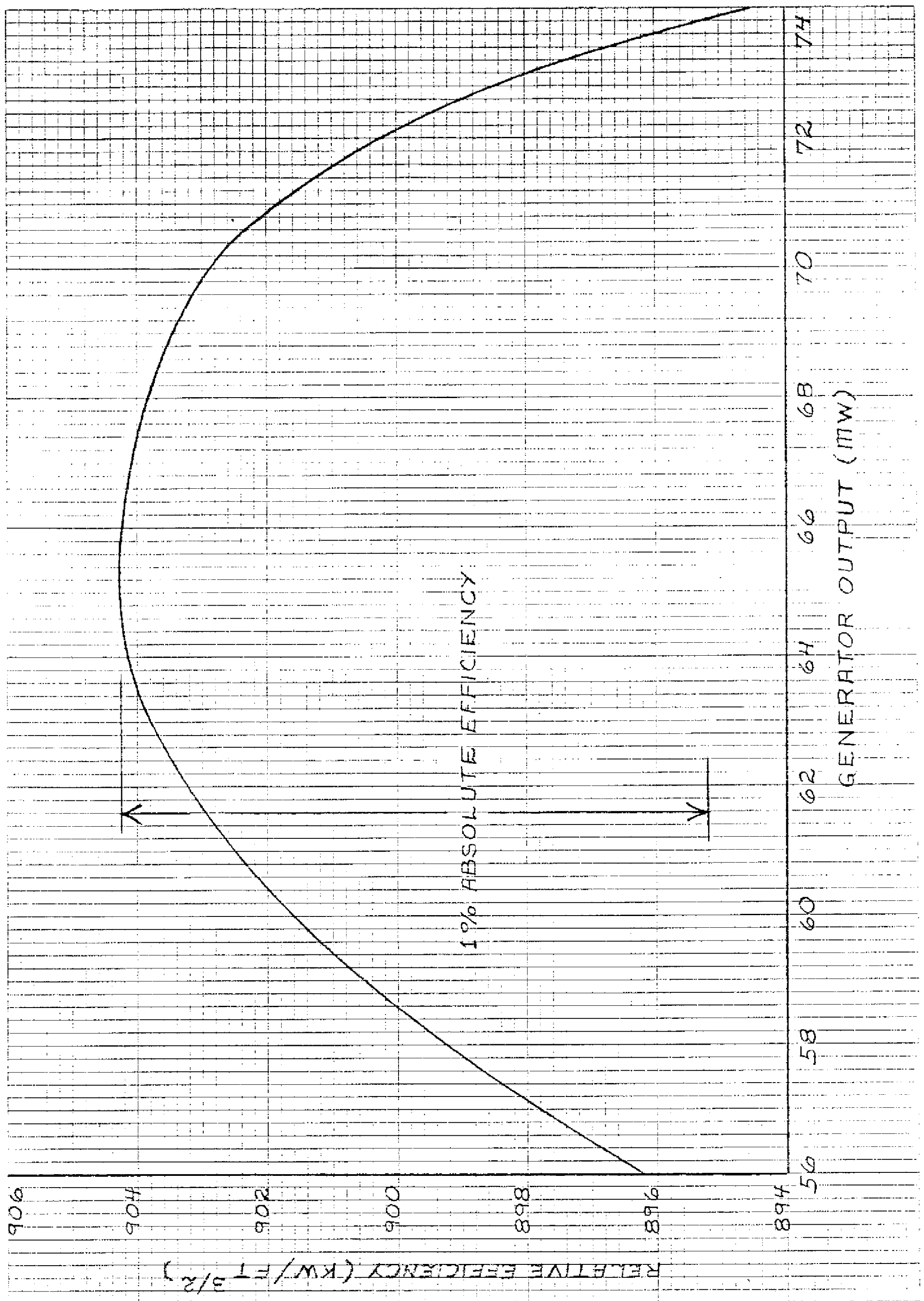


GRAPH 2



FLOW VERSUS POWER
SQRT of "D" & POWER Converted to 60 ft.
OPTIMUM EFFICIENCY
Generator Output (MW)
SQRT W-K Piezometers (ft^1/2)
50
54
58
62
66
70
74
78
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9

GRAPH 3


1% ABSOLUTE EFFICIENCY
GENERATOR OUTPUT (MW)
56 58 60 62 64 66 68 70 72 74
RELATIVE EFFICIENCY (KW/FT 3/2)
894 896 898 900 902 904 906

GRAPH 4