A NEW GRAPHICAL METHOD TO REDUCE TURBINE INDEX TEST DATA

Prepared by the HYDROELECTRIC DESIGN CENTER

NORTHWESTERN DIVISION

PORTLAND DISTRICT

US ARMY CORPS OF ENGINEERS

OCTOBER, 2006

PURPOSE

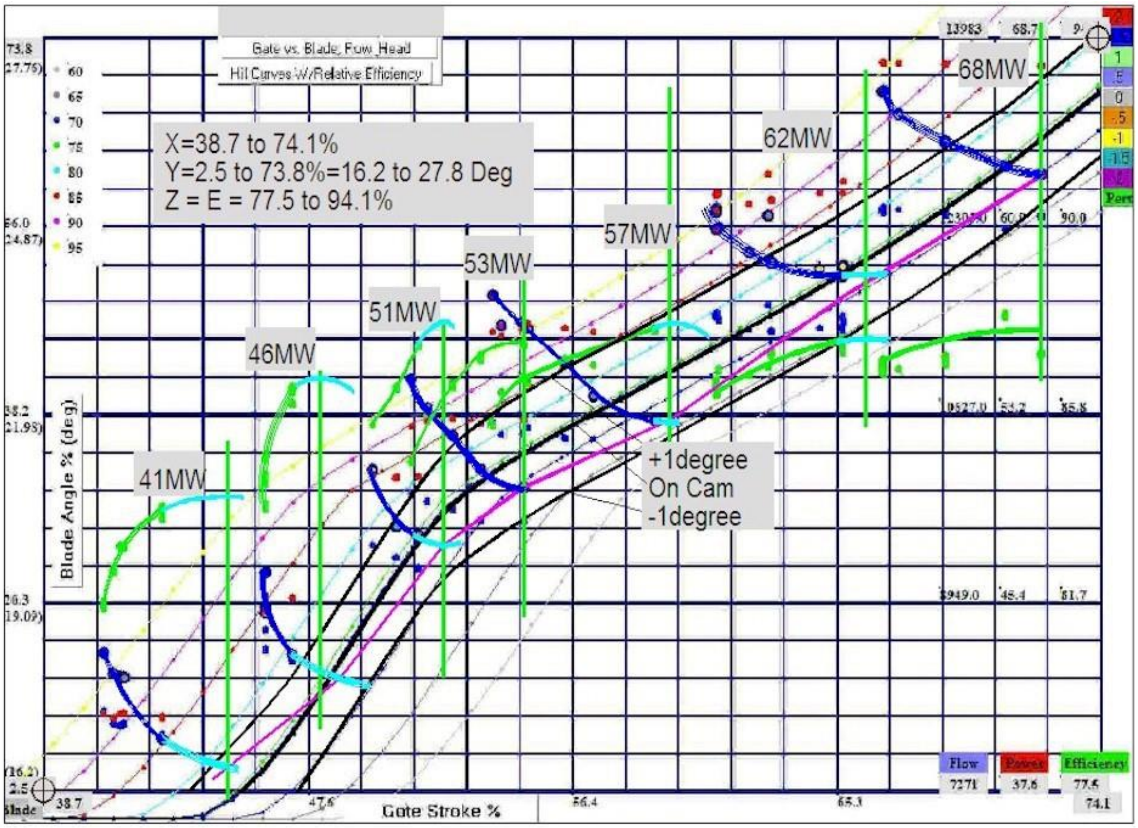
The purpose of this study was to develop a new method of reducing turbine index test data as recorded by the Index Test Box (ITB). In a conventional index test, blade angle is held constant and the gates are moved to different power levels. The ITB, however, is designed to record turbine performance data while the governor is holding power constant. It operates by perturbating the blades to move in a succession of small increments. After the gates have moved to their corresponding position to hold power constant, and after conditions have stabilized, the ITB will record selected data points. Therefore, the graphical method of reducing conventional index data recorded for fixed blades cannot be used directly. It must be modified to be able to reduce data recorded at constant power rather than at constant blade.

CONTRACTOR'S PROPOSED METHOD

In the contract for development of the ITB, the Contractor was tasked to develop a method to reduce the index test data the ITB would record. Accordingly, the Contractor proposed the graphical method as shown on Graph 1. The data used for this example is from the Proof of Concept test of the ITB on McNary unit #9 in December 2005. For the graphical axes: the left Y-axis is blade angle, the X-axis is gate, and the right Y-axis has three different scales – flow, power and efficiency. The Contractor had written a specific software program to provide the three scaled axes on the right Y-axis.

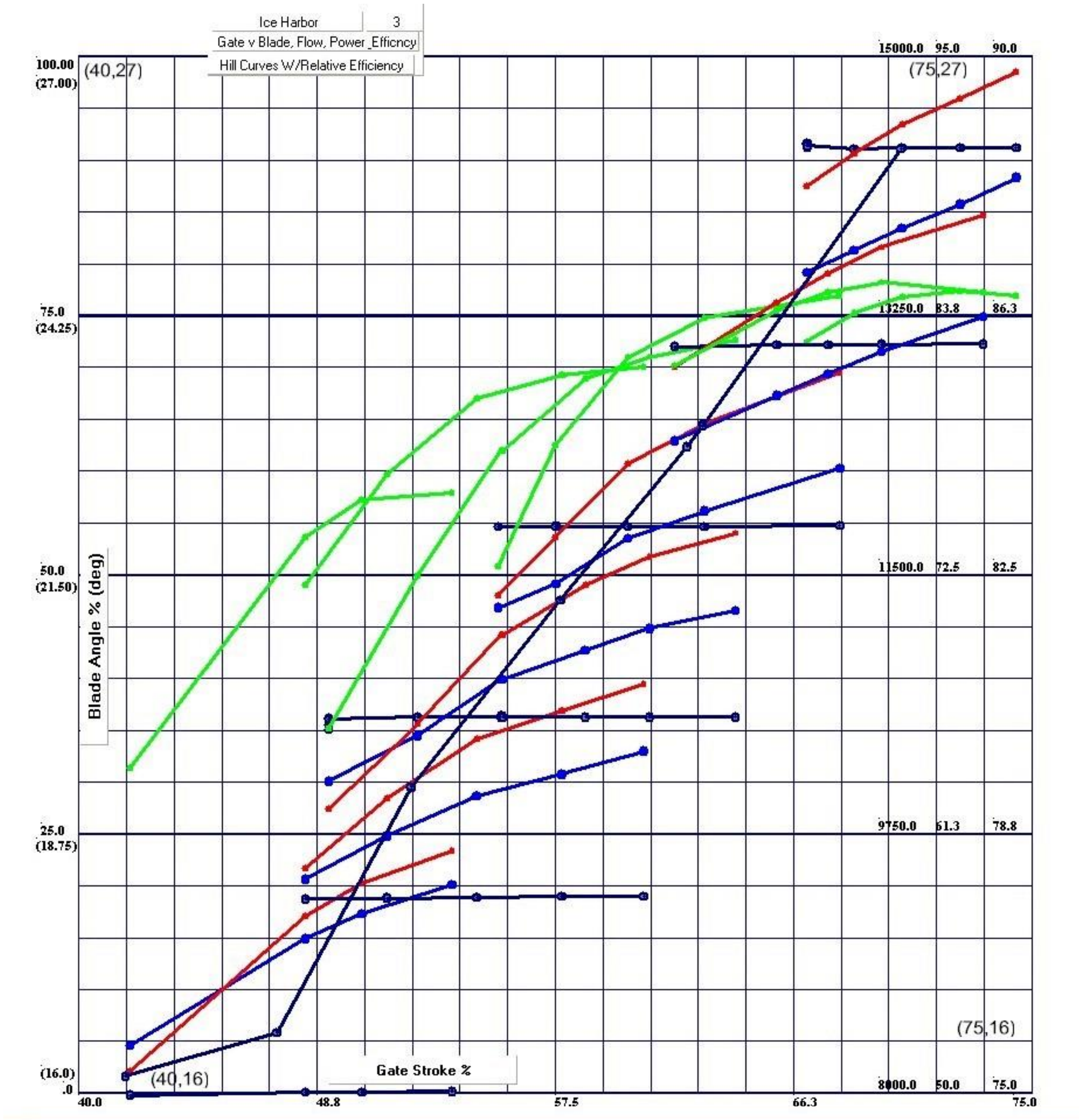
On the plot of Graph 1, the family of curves from lowest left to uppermost right is the cam curves presently installed in the machine. The short segments of red, horizontal lines are power; the similar blue lines are flow; and the black, convex upward curves are the gate-blade lines. Since the blade perturbation was restricted to a movement not to exceed $\pm$ 2 degrees, data was not recorded over a sufficiently wide range. Consequently, the Contractor was allowed to extrapolate the data for this demonstration purpose as shown in magenta. The green, fish hook lines, with the extrapolated magenta tops, are the relative efficiency lines for each series of constant power trials.

The manner in which this graphical format is used is to draw an envelope curve that is tangent to the relative efficiency curves. Then the intersected points of tangency are projected downward passing through the power, flow, and blade-gate curves. Connecting each of these loci of intersections gives the flow versus gate, power versus gate, and blade versus gate or cam curve.



Graph 1 Index Test Box display with December 2005 McNary index test

This same format may be used for conventional index test data as shown on Graph 2. Here, the data from a conventional test on Ice Harbor unit #3, recorded by the ITB without blade perturbation, is plotted. It is noted that the present cam curves in the machine were not plotted on this particular graph. The other two significant differences between this graph and the first graph are that the blade-gate lines are now horizontal because of the fixed blades and the power and flow smooth curves are curved upward rather than being horizontal.



Graph 2 Index Test Box graphing of Ice Harbor February 2006 Index Test

IMPROVEMENTS

It was realized that the Contractor's proposed graphical method could be improved by the smoothing techniques commonly used by the Hydroelectric Design Center (HDC). This improvement is shown on Graphs 3 thru 6. This is the same data from the index test on Ice Harbor unit #3 as used on Graph 2. On Graph 3, which is from an EXCEL file, the Contractor's graphical method is plotted. The exception is the right hand Y-axis has only a single scale. Therefore, multipliers were used on the flow and relative efficiency data to enable them to fit within the scaled axes and the relative efficiency axis is switched to the left Y-axis.

To apply a smoothing technique to this graphical data reduction, the power and flow versus gate data are plotted. Then for each fixed blade series of runs a cubic trend line is fitted to power and another to flow. These equations are then used to calculate a relative efficiency for every 0.1% gate for each series of fixed blade test runs. These relative efficiency profiles are then plotted on the upper portion of the graph.

The fixed scale on the Y axis would not allow sufficient expansion of these relative efficiency profiles, as can be achieved on the Contractor's graphical plot with separately scaled axes. Therefore, the relative efficiency profiles were replotted on Graph 2. On this graph, the original test points are overlaid on the computed relative efficiency profiles. This is done to examine if any of the test points had sufficient error to classify them as "outriders." All test points were sufficiently accurate and were retained in the data set. Next, the points of tangency on each fixed blade profile are determined by use of a French curve and noted by the black diamonds. These tangent points were then transferred back to Graph 1. Another advantage to this mathematical smoothing is that it can be used to extrapolate the data. For the steepest (26 degree) blade angle, the final test point was not at a large enough gate to fully develop the shape of the relative efficiency profile. Therefore, the cubic equations were used to extend the calculation of the relative efficiency values to a higher gate, as shown. For this purpose, the equations of the smooth curves are usually not higher than third order. Higher order equations are not well behaved beyond the range of the data on which they are based.

The final development of this graph is the same as on Graph 2. The tangent points on the relative efficiency profiles are projected down to intercept the corresponding power, flow, and blade to gate smooth curves for each fixed blade series. Then, these points of intercept are connected to yield the power to gate, flow to gate, and blade to gate or cam curves. For clarity, the blade to gate cam curve is replotted on Graph 3 and the power to gate and flow to gate curves are replotted on Graph 4.

CONCLUSIONS

It is concluded that this new graphical format is suitable for use in reducing index test data recorded for either a series of fixed blade trials or constant power trials. Further, it does not appear that power needs to be held precisely constant, but may drift slightly higher or lower. However, if neither blade nor power is held constant, this graphical procedure is not suitable. In the event that no parameter is held constant during an index test, a three-dimensional mapping program will be needed to reduce the test data.