INDEX TEST ANALYSIS OF GENERATING UNIT PERFORMANCE AT DORENA 1

2nd Index Test at 48 Ft

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INTRODUCTION

An analysis of the performance of the hydroelectric generating unit at Dorena 1 Dam was performed using a new Hybrid Index Testing Method. Suitable data was recorded en mass and provided to Actuation Test Equipment Co, Inc., (ATECo) for preliminary PostProcessing using the Index Test Box (ITB). The software programs associated with the company's ITB were utilized to sort the data, apply Affinity Law head corrections and average identical points as described in the next section. That data was then used in a test code specified manual manner to produce the index test curves and the blade to gate cam curve.

INDEX TEST BOX SOFTWARE PROGRAM

Description of the Index Test Box

The Index Test Box is a standard IBM® PC Clone computer running Windows 7®. The ITB software is a Visual Basic 6® program that is compiled to an executable program for distribution. Distribution, installation and operation are analogous to a typical video game program.

Data can be acquired several ways. Discreet sensors can be used in powerplants without a SCADA system using National Instruments® Analog/Digital Input/output boards and external I/O modules and any commercial datalogger to produce ".csv" files. Data can be acquired digitally from another instrument using any standard machine to machine communication interface. Preferred method follows OPC Foundation's communication protocols. Data can be digitized and recorded by another test system, such as a typical powerplant datalogger to record strip-chart type streamed data files that are transported as *.csv data files via CDs, disks, flash drives or over the Internet.

ITB Functions currently available include:

1. Stripchart-style recording of live-field data for later analysis.
2. SteadyState data analysis and collection of live field data.
3. Continuous Efficiency Monitoring of machine health.
4. Digitization of Cartesian coordinate charts of cam profile data
5. The ITB was designed for index testing Kaplan turbines; the ITB is also applicable to Francis and Pelton turbines.

The ITB was designed as an accessory to Woodward Governor's 3-D cam. The untimely demise of that organization left this new technology without a home so the Actuation Test Equipment Company was started up to carry this technology forward.

Description of Data Reduction Process

Data reduction takes place in several steps. The input “raw-data” is the continuous stripchart file from the *Woodward 505 HT PLC®* or powerplant data logger. The first step in the data reduction is to rearrange the columns of the raw-data file to conform to the ITB input format and then truncate it to just the time interval during which the index-test data was collected.

The data was normalized in its “rawest” form when it is read-into the ITB for SteadyState analysis by applying the code specified[1] affinity laws to correct for any head variations.

SteadyState points are gleaned from the continuous raw-data file using a sliding 100-sample window to bracket a block of data for statistical analysis. This analysis consists of a least-squares linear regression of the 100-sample block that draws a line through the “center of mass” of the data. The center point of this line is the “Average Value” for the data point and the slope of the line indicates its “SteadyState-ness.” Next a standard deviation is computed between the individual data points and the line to quantify data coherence.

To be deemed SteadyState, the slope of the line must be near-zero and the standard deviation must be small. Steady-state operation is detected when both Slope and Standard Deviation are within operator pre-set limits.

Results of the SteadyState analysis are output in three data file formats:

1. "AllData.csv" contains every analyzed data point.
2. “AllSSData.csv” contains only the “SteadyState” data points that are deemed to be steady-state.
3. The third output is a set of files that are named for the head, gate, blade, flow power and efficiency values of their contents. For example, the file named “H683, _G953, _B686, _F8056, _P352, _E756, _SSData.csv” contains all data points at 68.3 ft head, 953 gate, 68.6 blade, 805.6 cfs flow, 3.52 MW and a generating efficiency of 75.6%.

Data within all output files is arranged in chronological order.

The **AllData.csv** file will be analyzed further to develop an overall efficiency profile and new 3D cam profile line for 69 feet head. The **AllData.csv** file is a chronologically ordered listing of the SteadyState filtered ITB output with line breaks and column-averages placed wherever a non-SteadyState point is encountered. Consecutive identical test points are counted and the number added to the output as a figure-of-merit for the data point, the reasoning is that if the same value comes out many times in a row, then the data point is steady-state and the average values are

[1] ASME PTC-18 Pg. 64, Section 5, pp. 5.2.1

good and stable. Located at the bottom of the head, gate, blade, flow, power and efficiency columns in each data segment are the average value for that column.

In the next step the ITB program consolidates the averaged values in the "**AllDataNew.csv**" file into the "Results.csv" file to create a chronological listing of all of the averaged SteadyState points.

The final result of the ITB SteadyState process is the "Results.xlsx" file. The data was sorted again to remove the SteadyState points that aren't in a consecutive string of 10 or more SteadyState points to leave only the longer dwells that are indicative of the intended test points. This data is parsed at each blade and gate change, averages are computed for each segment and then a Cartesian coordinate graph is drawn to show the results (Figure).

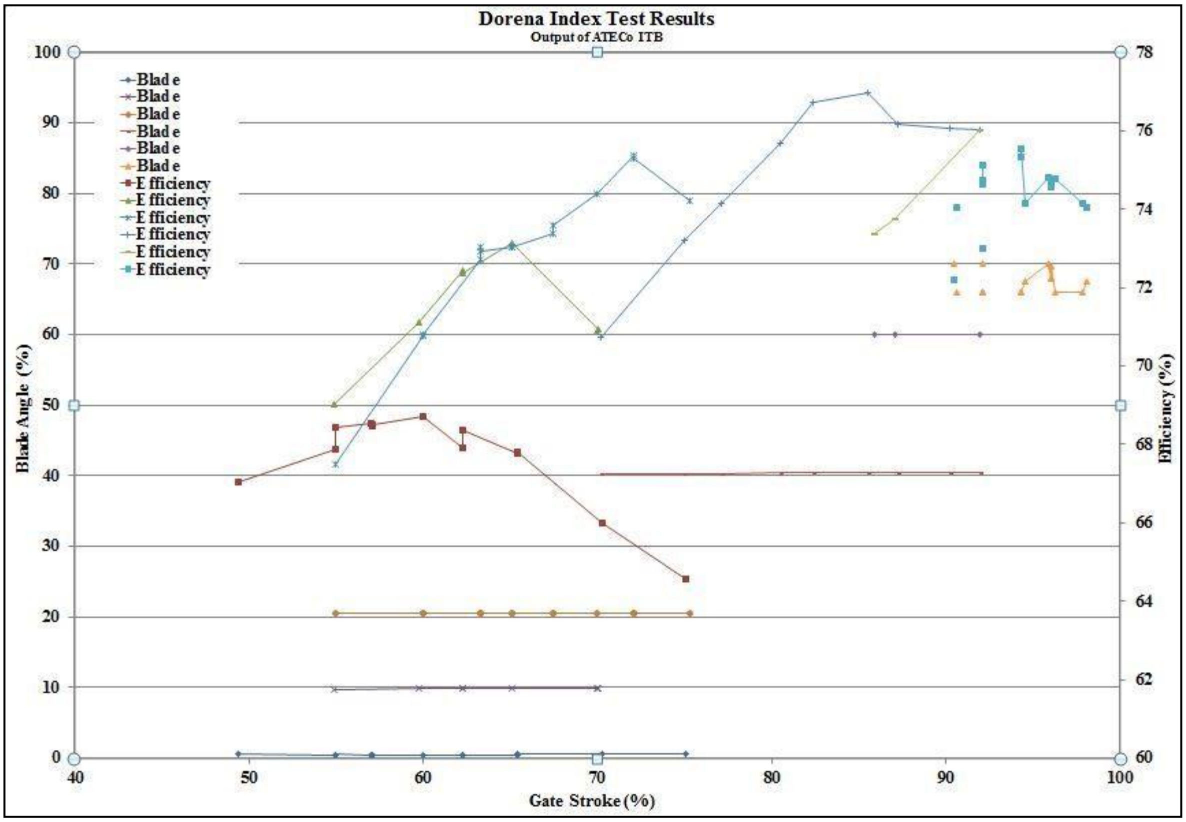

Figure 1 Index Test Box Output Results for Dorena test data

MANUAL METHOD OF DEVELOPING INDEX TEST CURVES

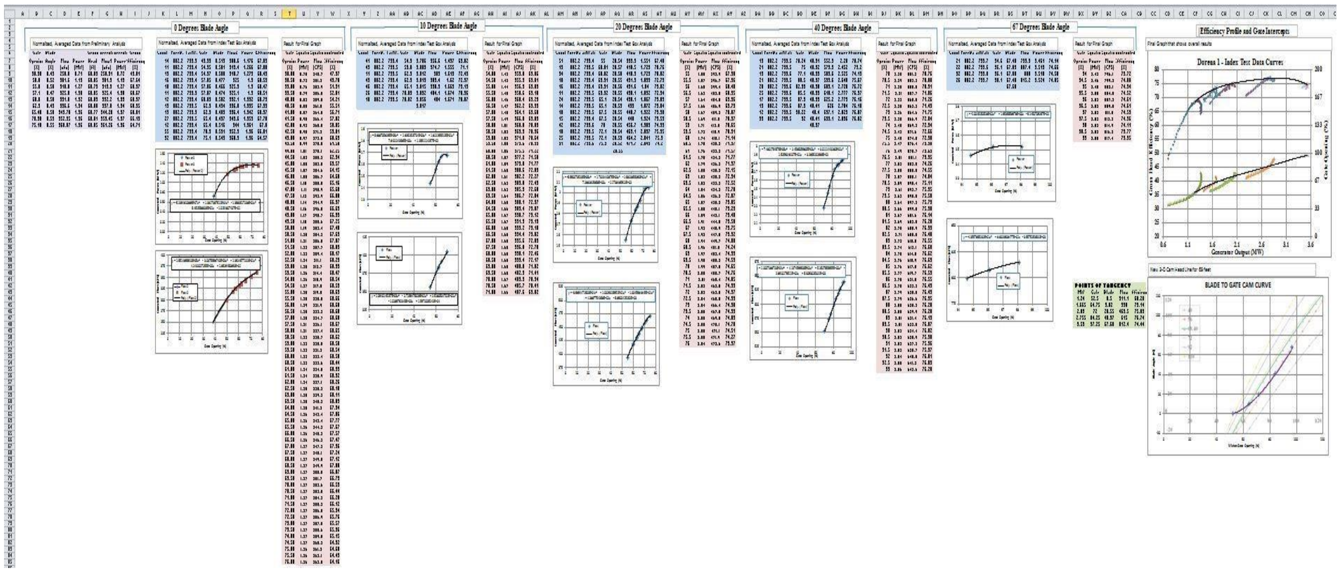

Figure 2 Dorena Index Test Analysis Spreadsheet

Figure 2 shows the layout of the data in the final spreadsheet. (Click on the image to download the spreadsheet.)

In a manual index test, the blades are held at a series of fixed pitch angles and the wicket gates are opened sequentially at each blade angle. Figure 3 shows an overview of the raw data indicating the blade and gate positioning and gross unit efficiency for the test.

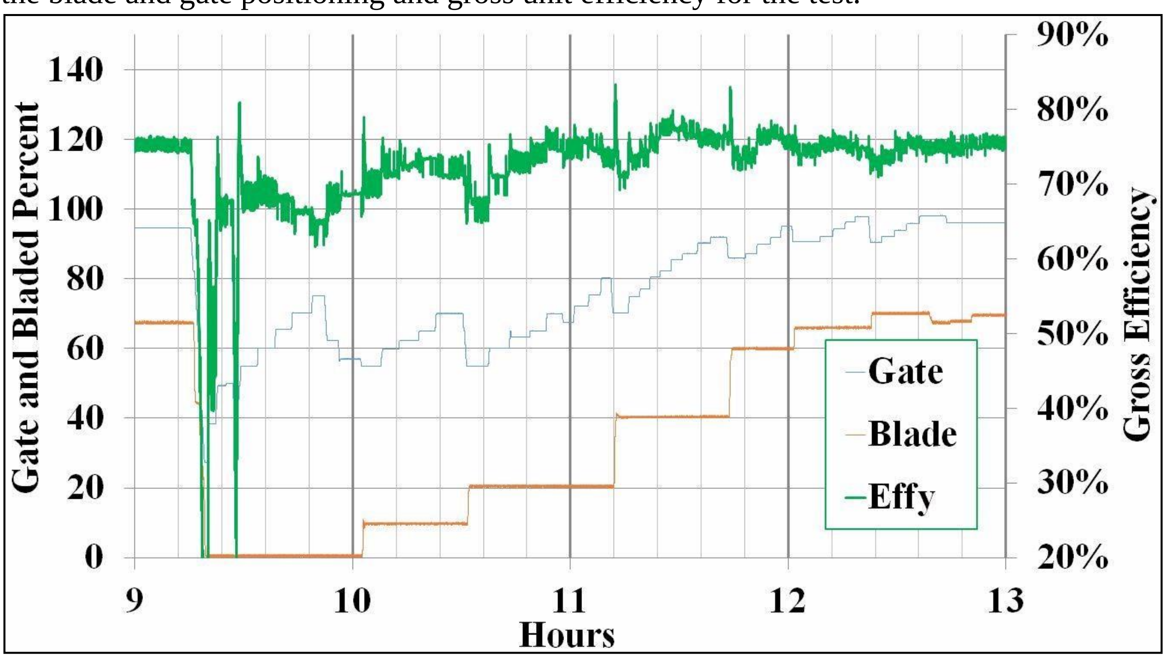

Figure 3 Big Picture of index test points

At each blade/gate pair test point, a 3-5-minute dwell is waited out to allow everything to settle out before a data point is recorded.

In the new Hybrid Index Test method adopted for this test, a large number of readings are streamed to memory for subsequent off-line ITB PostProcessor SteadyState analysis that consists of a linear regression by least squares fit and standard deviation for each blade/gate pair. These form a data set for every individual fixed blade angle as shown by the blue highlighted tables in Figure 2.

The next step is to plot power and flow versus gate opening separately as two "smooth curves," shown located directly under each blue data set. These graphs are used to check for any random or precision errors.

All of the data provided by the ITB software was very precise with no randomness evident.

Next the data was recombined and the performance values computed for every 0.5% of gate opening as shown with the light pink highlighted data tables on Figure 2.

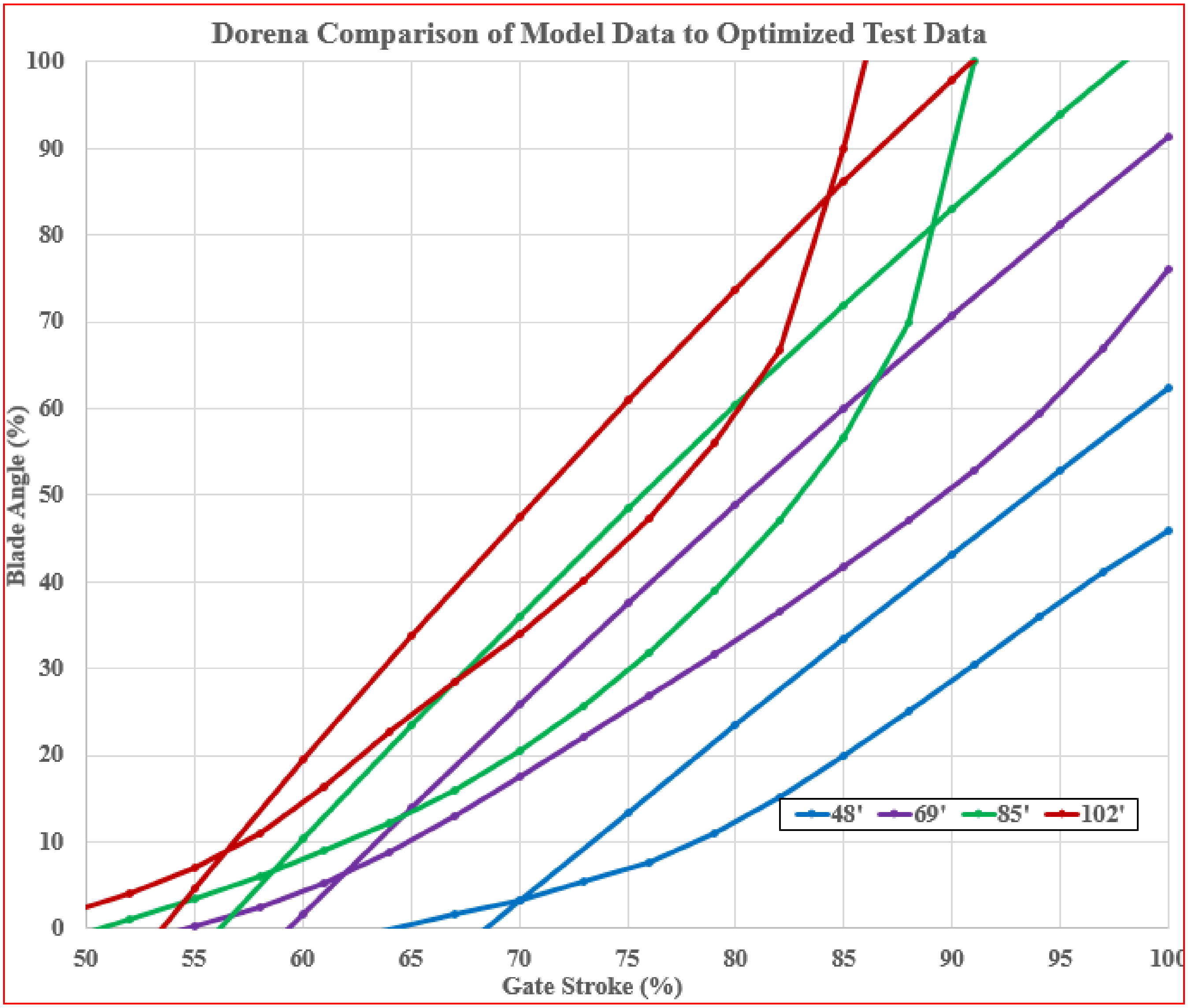

Figure 4 Comparison of Test Heads to Extrapolated Big Picture of index test points

The single data table at the far left that is highlighted in light purple is the input from the ITB software and was compared to the hand calculated data set above by plotting it right on top of the two 0-Degrees (flat) blade angle smooth curves to verify and demonstrate the accuracy of that ITB software.

Observations and Conclusions

- On the upper portion of the **Dorena 1 - Index Test Data Curves** graph a tangent line is drawn connecting the tangents of the fixed blade profiles.
- This graph shows the overall efficiency performance of this machine at a gross head (forebay - tailwater) of 69 feet.

- This means the intake losses, the hydraulic losses in the penstock (friction and turbulence from sharp direction and diameter changes) and the sudden expansion losses of the fluid exiting the draft tube are all charged to the turbine.
- This unit has a maximum efficiency of 76.7% at 2.9 MW where it is using 645 cfs.
- The accuracy of an index test data reduction can be judged by the lack of randomness in the line of interpolation points on the lower portion of this main graph.
- All of the data points fall on the smooth curves which exemplifies the extreme accuracy with which this index test data was reduced.

- The tangent points of blade and gate are plotted onto the lower graph and a line drawn through them to form the "blade to gate cam curve."
- Again, this data shows no randomness whatsoever.
- It does show the lift off point for the blades at this gross head is 52.5% gate opening, which is a significantly large gate opening, and that full steep blade angle is not achieved until 97.25%.
- These two characteristics, along with the low maximum efficiency (even when including the penstock losses) indicate that design head or the head of best efficiency will be noticeably higher.

End Of File