In the December 2005 field test, the most vexing problem that prevented us from running the ITB's preferred **"Constant Power"** index testing method (which is the primary testing method that the ITB is designed to perform) was the hydroelectric unit's inherent instabilities that are caused by the excessive deadband and deadtime that *are intentionally programmed* into USACE's sub-standard GDACS 3-D cams and blade controllers.

The turbine control equipment was designed by HDC and deployed throughout FCRPS by HDC's "captive supplier," ACSI. In deference to the HDC Response statements, the ITB perfectly executed the Constant Power testing method in 1985 and again in 1987 while I was developing this technology for Woodward Governor Company for use with Woodward's digital electronic 3-D cams (as described below). Systemic problems inherent with the GDACS 3-D cam were the reason we could not perform the "unattended index test" mentioned.

Kaplan Blade To Gate Parallelogram Spiral

During our August 2004 visit to ACSI, after I explained the manner in which the ITB tested a unit along the Constant Power lines of the turbine's operating envelope, Dan Perrier (President of ACSI) explained to Lee Sheldon and me why the Index Test Box's Constant Power method couldn't work with the GDACS control systems.

Dan explained the behavior and mechanism of the GDACS 3-D cams and how the inherent instability occurs, and why it would prevent my Constant Power index testing method from working.

From his explanation it seemed that he felt this was <u>normal behavior</u> for all Kaplan turbine governors, 3-D cams and blade controls, instead of being a <u>unique problem</u> with HDC's self-inflicted, sub-standard GDACS 3-D cams and control systems.

Dan was trying to discourage me from attempting to use the ITB Constant Power method to define the optimum cam surface with his descriptions of the GDACS 3-D cam's odd "parallelogram spiral" motion *(recounted below).*

It was Dan's assertion that the one-degree deadband and 35-second deadtime programmed in the GDACS 3-D cam blade control systems (that I witnessed, and Rod Wittinger documented in his McNary field test memo) are normal for Kaplan hydroelectric turbine control systems, are the root cause of this problem (I agreed this is a root cause) and would preclude any Constant Power testing of these units (I also agreed it would prevent Constant Power testing). I disagree that these deficiencies are "normal" for hydro-turbine control systems, they are unique to the Corps of Engineers' control systems.

These <u>intentionally added blade control system deficiencies</u> are meant to mask inherent control system instabilities that would make the units continuously hunt and wander during normal operation. This unwanted motion prematurely wears out the blade mechanisms and trunion bearings. When the trunion bearings wear out, the turbine runners start leaking oil from the Kaplan hub into the water. It is known to me that in several instances the USACE corrective action for this problem has been to weld the runner blades in place at a fixed angle and remove the oil from the hub, thus rendering these Kaplan turbines into "fixed-blade" propeller turbines. This is disgraceful.

Dan's explanation of the GDACS 3-D cam behavior went like this (ref fig 9, below):

> When a large upward SetPoint change is made in power,
>
> Starting at (a.) on fig 9, the governor's speed motor is activated to raise the SetPoint by the GDACS control system,
>
> Gates open rapidly to get the power output up to the new SetPoint level at the constant power curve at (b), with the desired target operating point at (e) on the on-cam line.
>
> Power output is sensed by the GDACS control system, which continues opening the gates until the generation SetPoint demand is satisfied at (b).

During this first move, the blade to gate motion tracked the linear taper of the mechanical 2-D cam on the gate restoring shaft of the governor, tracing the line from (a) to (b) instead of tracking the “on-cam line” from (a) to (e) like a proper governor and 3-D cam should.

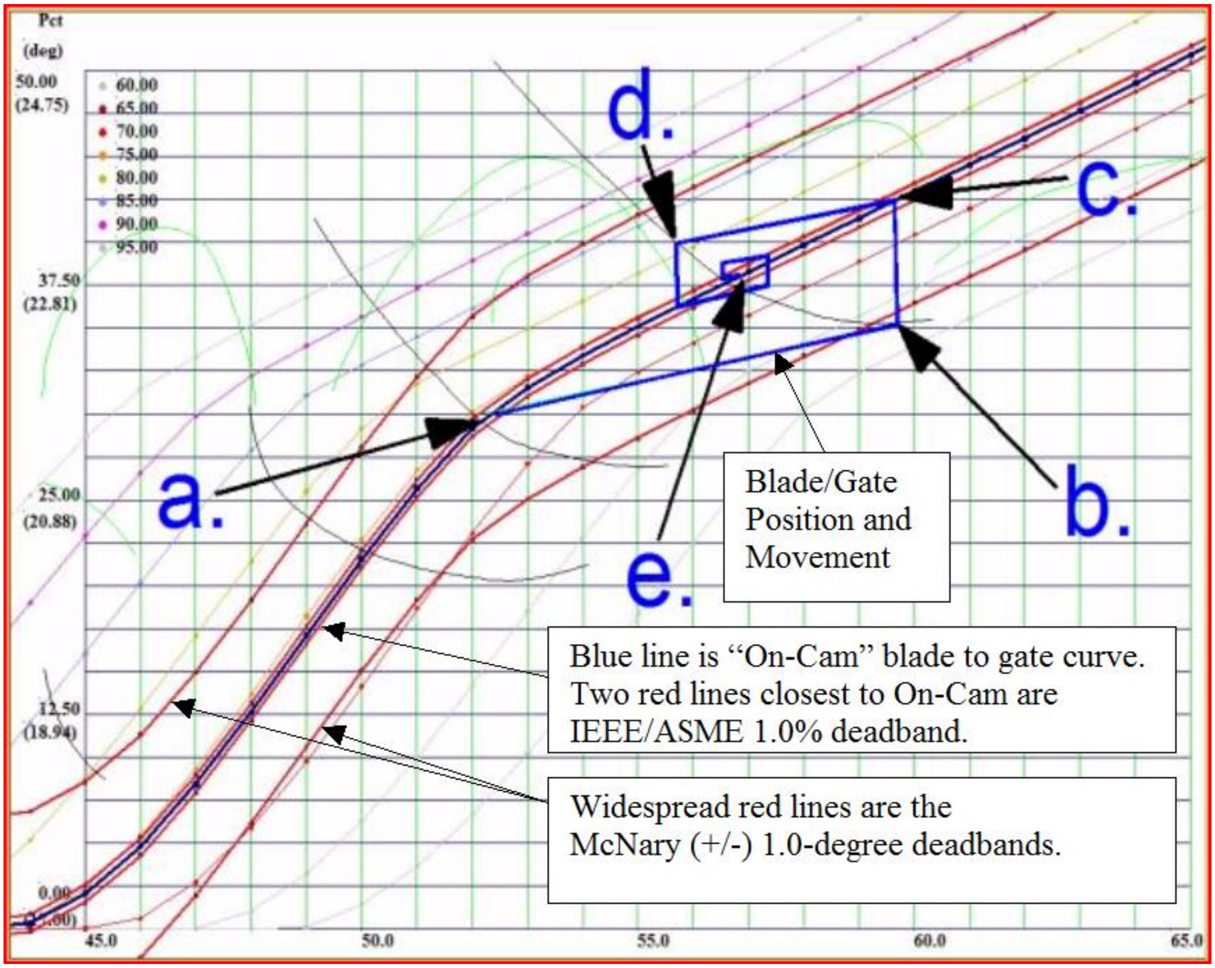
Due to the 35-second deadtime in the blade control system, the stepper motor does not move during the motion from (a) to (b), so the blades move only along the linear taper of the metal 2-D cam that is mounted on the gate restoring shaft. This causes the gates to open farther than they would have had the blade controller been robust and accurate, and the blade angle been able to track the on-cam curve from (a) to (e).

The blade controller wakes-up 35 seconds later, takes note of the change in gate position and then computes the new Ideal Blade angle, and then moves the stepping motor to complete the blade motion to the new Ideal Blade position for the existing gate at 75 ft head at (c) as dictated by the 3-D cam algorithm and the cam-data surface lookup table.

When the blades move up to this new, steeper position, power output of the unit increases significantly, exceeding the deadband set for the power level controller in the GDACS, so the closed loop on power in the GDACS pulls the gates back to get power back to the SetPoint at the constant power curve that extends from (b) to (d), and beyond.

After another deadtime of the GDACS load feedback, the speed motor is moved again to decrease power back down to the load SetPoint at (d). Again, the blades do not move in unison with the gates to track the “on cam line” from (c) to (e) because of the 35-second deadtime, so the blade to gates motion tracks the linear taper of the metal cam from (c) to (d) on the way down.

This motion continues until the blades are within the 1.0-degree blade deadband programmed into the Panel Mate touch screen control panel, then the blade controller stops making corrections to blade angle.



Blade/Gate Position and Movement

Blue line is "On-Cam" blade to gate curve. Two red lines closest to On-Cam are IEEE/ASME 1.0% deadband.

Widespread red lines are the McNary (+/-) 1.0-degree deadbands.

Figure 9 Parallelogram spiral motion of Kaplan blades with GDACS 3-D cam plotted over McNary WithScreens 3-D cam profile surface.

The cause of this "rectangular spiral," (or to better characterize the impact this misalignment would have on flow turbulence & shear forces in the water and on any fish passing through the turbine during this sequence, we could call it a *"rectangular death spiral"*) is the bad dynamic behavior of the USACE designed blade actuator in the GDACS 3-D cam. To mask this problem, the control system was desensitized by adding a 1.0-degree deadband that prohibits blade motion if the blades are within 1.0-degree of the Ideal Blade position. This results in a permanent and continuous 6.5% blade position error away from the Ideal Blade position. (ASME/IEEE standard is 0.5%) There is also an associated deadband and deadtime on power level in the GDACS control system. These deadbands and deadtimes are a very crude method of desensitizing the turbine control systems so the machines' unwanted motions don't wear out the trunion bearings due to the inherent instabilities that the USACE HDC GDACS 3-D cams introduced.

No commercial customer would ever put up with such shoddy engineering practices. Only the Government could come up with such an awful fix for a problem, call it "close enough for Government work," and then cover it up for 9+ years in the face of a Federal Endangered Species lawsuit over a "fish-mortality" problem that is most definitely negatively affected by this situation. If these were airplanes or ships, this level of engineering malfeasance would never be tolerated.

To minimize the consequences of this problem, the operators change the generation SetPoint very slowly on these units so that the 3-D cam and blade control systems can keep up. For a direct comparison, ["a properly robust and accurate control system on a large Kaplan turbine should be able to go from speed-no-load to full power in about 10 seconds - these USACE systems in FCRPS cannot come anywhere near that level of performance.

The 1.0-degree deadband programmed into the GDACS 3-D cam, when evaluated per the ASME PTC-29 deadband measurement technique which *sums the residual error on both sides of the optimum cam line,* becomes a 12.9% deadband. When this is added to the anticipated 2.0% deadband from mechanical hysteresis of the blade positioning system of these 50+ year-old machines; *the deadband is about 15%.*

IEEE Std-125 quantifies an acceptable deadband at 1.0%, a standard that all other hydroturbine 3-D cam and blade control equipment suppliers meet or exceed. This is not a mandate, however, just a guideline indicating what is reasonable and customary throughout the industry for contracting agents (such as USACE's Contracting Office in Portland) to use in specifying hydroturbine control system equipment in the acquisition documents. It is incumbent upon the Contracting Officers to mandate that the equipment be in compliance with the industry-accepted nominal standards.

The failure of the Contracting Officers to include the applicable industry standards in the acquisition documents for this equipment does not excuse the extreme substandard condition of this equipment, especially in light of the Endangered Species Act lawsuit regarding fish mortality in FCRPS. The Endangered Species Act requires that only the "Best Available Science" be used – not by any stretch of the imagination does the above-described GDACS 3-D cam blade control system fit that description.

If other suppliers can achieve the industry standard's level of robustness and accuracy, why is it that USACE is accepting such an inaccurate and unstable system from HDC and ACSI? The consequence of this misalignment is exacerbation of the fish mortality problem that environmentalists, Native Americans, politicians and a Federal Judge are so upset with USACE about. It doesn't have to be this way!

I had a professor in college who described business relationships such as the one between HDC and ACSI as ***"industrial incest."*** *Not a very flattering name, but quite descriptive of what is going on. This situation was brought to Charlie Allen's attention in a letter of October 6, 2006. HDC's position to me in response to that letter was that the status quo is close enough for Government work, so I should just let it be.*