MAHOGANY GOVERNOR CAM

George was standing in front of the governor control panel undertaking pre-commissioning dry tests on an 8MW, 90m. head Francis turbine equipped with a Howell-Bunger relief valve, and the equipment was not performing as expected. He had arrived three days previously at the tropical site, where a low concrete spillway dam across the river diverted flow into a gathering tube intake, after which there was a 2,500m woodstave pipe to a surge tank on top of a hill, followed by 780m of steel penstock to the powerhouse. The facility was designed to operate unattended, with power output set by a float control in the headpond, where there was one meter of storage. When the headpond was full, the float initiated the start-up sequence by opening the turbine rotary valve, then the wicket gates to speed-no-load, followed by synchronizing and slowly opening the wickets to the peak efficiency point at about 90% gate in the wet season, and to about 60% gate in the dry season. When the headpond was empty, the reverse happened.

With both a surge tank and a relief valve, the hydraulic controls were quite complicated, and George, with an assistant, had spent about 2 months calculating the necessary generator inertia, the optimum size for the relief valve and timings for the valve and wicket gates to limit waterhammer to within +/- 20% and speed rise to 45%. As a result, the governor had 2 speeds, a rapid movement to 15% gate to obtain a quick breakaway on the thrust bearing, and afterwards a very slow opening rate of over 60 seconds to limit waterhammer. For closure on detection of a fault, the movement was rapid, in less than 10 seconds, while the relief valve opened at the same time. Normal closure was in 60 seconds, and the relief valve did not open.

In the dry tests, George was determining the extent of relief valve opening for various rapid load rejections. It had to be exactly as calculated to be within waterhammer restrictions. Unfortunately, the valve was not opening to the correct position at intermediate load rejections, despite simulation of all controls in the "wet" position, including the governor ballhead propped up to the synchronous speed position to center the pilot valve. A review of the control schematics indicated that the shape of a stainless steel cam in the relief valve controls must be at fault. The cam rotated through about 90 degrees as the wicket gates moved to full open. As the cam rotated, a small roller lifted to move a pilot valve, which controlled the relief valve servomotor, to a position corresponding to the required maximum relief valve opening. George tried rotating the cam on the shaft, but to no avail. The shape of the roller surface on the cam had to be modified to include an indent at about the half load position. Discussing the problem with the turbine erector, it was decided to substitute a pine wood cam, to be shaped by trial and error. George then used a file to shape the cam to the required profile based on numerous dry tests. For the wet tests, a hard mahogany cam was substituted, cut to 2mm. above the pine wood profile, leaving some wood for final shaping.

The wet tests proceeded cautiously, with the powerhouse pressure gauge marked with red tape at the design waterhammer pressure linits. Pressure gauges were also installed at the quarter points up the length of the penstock. Load rejection tests were undertaken at 5% gate increments, and the mahogany cam was carefully filed down until pressures were within design limits. The turbine erector then used the mahogany cam to shape two steel cams cut from discarded checker plating. Both were tested and finally shaped with a grinder. One was returned to the manufacturer as a model for a stainless cam, installed a few months later.

What had gone wrong?. All the powerhouse equipment was supplied as a water to wire package, but the manufacturer did not possess the necessary expertese to calculate either the interaction of the turbine and relief valve, nor the automatic control sequences. This work was undertaken by the consultant, who was provided with turbine hill charts and head-valve-opening discharge graphs for the relief valve. A further complication was the use of an American governor with european equipment, so that governor and turbine did not meet until at site. As a conequence, the manufacturer elected to provide a generic cam which bore no resemblance to the final cam, since the cam could only be profiled by trial and error once all the hydraulic controls had been assembled at site - a situation not revealed to the consultant.

Lessons Learned.

There are several lessons in this case. First, it is far preferable to have all design responsability in one one contract for water-to-wire contracts, and not split between manufacturer and a consultant. Secondly, in this case the equipment contract had been awarded before the consultant was hired, another negative influence on the performance of the work. And thirdly, for projects where there is a relief valve attached to the turbine, the interaction of the two is so complex that valve, governor and turbine should all be assembled at the manufacturer's facility for dry testing before being shipped to site.