Air Void Testing for Safety-Related Feed Pumps in Nuclear Power Plants

Written by: Dr. T. Ravisundar, Ravi Somepalli, and Bill Nagle of HydroAire Inc.
Publisher: Pumps & Systems / December, 2011

An Interesting Challenge and Cause for Collaboration

A major nuclear power company approached an independent Pump Performance Test Lab in Chicago to discuss a series of tests for their Pacific 4" BFIDS in safety-related service. These auxiliary feed water (AFW) pumps were utilized in two pressurized water reactor plants to supply backup cooling water to the steam generators in the event the main feed water source was interrupted. The plants had been designed to utilize an air void between two motor operated valves to keep separate two different suction sources to the pump. The Nuclear Regulatory Commission (NRC) guidelines dictated that no more than a 2% air void could be passed through the pump to reliably assure its safety-related function. The nuclear power plant engineers believed the pump could ingest a greater margin of air without damage or impairment to pump performance. The NRC gave the nuclear power company an opportunity to demonstrate the capability of this pump by allowing them to conduct and monitor a series of transient air-void tests at the independent Pump Performance Test Lab.

Engineers Working Together to Define Test Scope

The nuclear power plant engineers worked closely with the engineers at the Test Lab and a third party engineering consultant to develop the scoping document which defined the tests needed to demonstrate the pump's capability under a range of scenarios. To design these tests, the team first reviewed the system configuration at the plants.

For added safety, each unit at each plant had one motor driven and one diesel engine driven AFW pump. Each AFW pump had been installed and aligned through valves and piping to take suction from either the non-safety related condensate storage tank (CST) or the nuclear safety related essential service water system (SX). The SX system is the nuclear safety related system that is connected to the plants ultimate heat sink (UHS), which is raw river water. As can be imagined, there is considerable difference in the purity of the water between the CST water and the SX water. Therefore, both plants intentionally built in the air void as a provision for separating these two systems to reduce the chance of SX water contaminating the clean condensate side of the system.

After thorough review, the team issued specifications for ten different sets of test cases which encompassed several operating conditions and well over 35 test scenarios. The tests would cover injection of different void volumes into the pump operating with several variables, some of which included different flow rates, suction pressures, and pump statuses (i.e. operating pump, idle pump with a pump start while suction is being transferred, etc.).

Configuring the Test Lab

Once the scope had been clearly defined and agreed upon, the Test Lab engineers set out to configure the Test Lab in a way that would duplicate almost identically the plant's AFW suction piping set-up. Within 10 days, the Test Lab was configured with a booster pump installed with a variable frequency drive to simulate the SX system as closely as possible so that the safety-related AFW pump could be operated within the same environment as it would function in the plant. The SX water source came from the Test Lab's 38,000 gallon suppression tank which was fed through the booster pump. The CST, which was simulated by the Test Lab's suppression tank, was not sent through the booster pump.

Both of the nuclear power plants knew that mussel shells would pass through the pumps due to the SX river water source, and the plants had been facing issues with pump downstream valves getting clogged with shell fragments. At the Test Lab, two different types of shells from each plant's river water sources were purposefully run through the pump during testing. This was done to examine how the pump and valves might perform in an actual real-life plant situation. The pump, a hearty 10-stage beast, chewed up the mussels without any problems. The Test Lab engineers used a 3/32" strainer to capture the sizable shell fragments. What is seen below is the small portion of shells captured by the strainer.

The remaining shell bits were ground-up by the pump smaller than 3/32".

Monitoring by the NRC

The independent Test Facility had set up a live video feed to show the pumps on the test stand as well as the real-time data streaming from their data collection software. The NRC and other members of the nuclear power company's team monitored the series of tests from a more comfortable room where visitor safety could be ensured.

Test Results

- The tests showed that the pump hydraulic performance did not degrade for voids up to 2.70 cubic ft. if the flow rate is low.
- Momentary degradation in hydraulic performance occurs for voids at high flow rates.
- Momentary degradation in hydraulic performance occurs for small voids at higher flow rates only if the voids are ingested while suction pressure is still increasing. If suction pressure increases to a value close to the SX pressure prior to ingestion, no effects on the hydraulic performance are noted.
- In each test, the pump performance recovered completely after the void had been cleared through the pump.
- To simulate a nearly deadheaded condition in the plant when the check valve closes due to high back-pressure provided by the steam generators, a conservative test was run. In this test, the suction piping from the SX swap-over valve and the pump was completely drained and the pump was almost entirely drained to introduce air in the pump stages. The pump was started in this partially drained condition with the discharge control valve throttled to simulate the minimum flow recirculation line. This test showed that the pump was able to re-prime itself and establish adequate flow/head following the transient.
- The rotor dynamic performance of the pump remained unaffected by the void ingestion in all tests. The bearing lateral and axial vibrations, rotor axial running position, and bearing temperatures remained unaffected by the void ingestion.

Based on the results of the tests, the third party engineering consulting firm made the following conclusions:

  - Based on a pump hydraulic performance test performed after the completion of thirty-five void tests which included voided conditions beyond what could have occurred in the plant, the pump showed no signs of mechanical damage or degraded clearances.

Therefore, the pump design is robust.

- Even if decrease in the discharge head and flow occurs, the decrease would be temporary and the interruption in the flow to the steam generators would be short-lived.
- The tests show that the AF pumps would have performed their design function adequately without permanent decrease in performance or damage.

Conclusion

This testing capability and nature of the Hydro to collaborate with pump users was a great asset to the nuclear company as they were able to demonstrate their pump's capability under bounding air-void conditions. Though the schedule was extremely aggressive, Hydro's Test Lab engineers were able to perform nearly 40 void tests within a 10-day period. The Test Lab engineers met all the objectives and are interested to see if and how these test results will affect future NRC regulations.