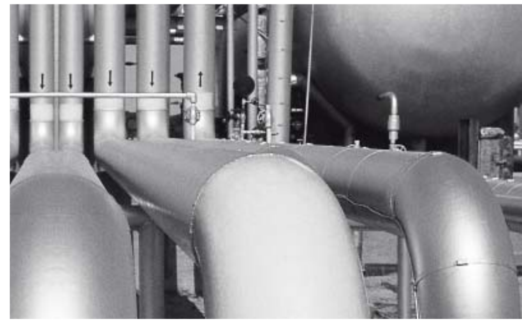
SMARTSIGNAL_TECHNICAL PUBLICATION SERIES

IMPROVED EQUIPMENT CONDITION-MONITORING SOFTWARE



smartsignal®
ELIMINATE FAILURE_

Improved Equipment Condition Monitoring Software

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Abstract

Arizona Public Service Company's Palo Verde Nuclear Generating Station used SmartSignal eCM (Equipment Condition Monitoring) to detect reactor coolant pump seal degradation months much earlier than conventional monitoring techniques. SmartSignal eCM models provide early warning of key component failures on the three Palo Verde electrical generating units. Existing monitoring techniques require 10 to 15 psi shifts in seal staging pressure to confirm seal degradation. SmartSignal empirical modeling techniques correctly identified a 5-psi shift as degradation of one of the triple redundant seal stages nearly two months earlier than the traditional monitoring system.

Introduction

The Reactor Coolant Pumps, key components of the Combustion Engineering Pressurized Water Reactors used at Palo Verde, transfer high-pressure water from the reactor to the steam generators. At Palo Verde, the high flow, low head 8780 horsepower vertically oriented reactor coolant pumps utilize 30-inch suction and 30-inch discharge pipes to pump 114,625 gallons per minute.

Figure 1 shows the layout of the seal system on a typical Palo Verde reactor coolant pump. Located within the containment building, the pumps ensure safe and efficient operation of the nuclear power plant. Palo Verde's designers included many redundant systems to ensure continued safety should unexpected equipment degradation occur. For example, each reactor has four reactor coolant pumps to ensure adequate heat removal from the reactor. Furthermore, each reactor coolant pump uses a three-stage seal mechanism to contain water inside the reactor coolant system. Although the reactor coolant pumps do not produce high head, they operate at a suction pressure of approximately 2500 psi. Therefore the reactor coolant pump seals have a strenuous and important job.

Motivation

Since the reactor coolant pumps operate within the containment building, physical access to the pumps occurs only during refueling outages. Engineers depend on process variables transmitted to the control room and through the station's data historian to assess the pumps' condition during normal operation.

Pump and seal maintenance occurs only during refueling outages carefully planned months in advance. The sooner that maintenance work is scheduled, the more efficient are the planning, procurement, and logistics. The costly reactor coolant pump seals require a lengthy procurement process. Early warning of seal degradation allows more time to plan the replacement. If significant seal degradation occurs without warning and requires an unplanned outage, replacement costs increase ten fold or more.

Furthermore, accurate assessment of the pump condition also helps determine whether maintenance deferral is possible. For example, if the reactor coolant pump seals show no signs of degradation, Palo Verde could use the increased monitoring capability provided by SmartSignal to extend the replacement interval.

Methods

The SmartSignal eCM software uses actual process variable measurements to construct empirical models of key equipment components at Palo Verde. During the modeling process, engineers evaluate equipment functions and identify key failure modes. Using this information, they create empirical models from historical data to capture normal operational behavior. In real time operation, the model uses actual measurements to generate estimates of expected values for normal operation. A residual value is the difference between the actual and the estimated values. Statistically significant residuals imply abnormal deviations that can be linked to expected failure modes.

The first column of Table 1 lists the eleven key process variable measurements for a typical reactor coolant pump seal that were identified during the modeling process. The independent variables - reactor coolant pump discharge pressure and seal water inlet temperature - describe the range of possible states for the reactor cooling pump seal. The SmartSignal eCM seal model accounts for normal variance in pump discharge pressure and seal water temperature to highlight seal mechanical degradation.

Table 1 maps three expected failure modes for the seals onto the eleven process variables. The table indicates a fault signature as process variables deviate from expected value in the high (+) or low (-) direction depending on fault type. For example, first stage seal degradation is indicated by a positive residual in Controlled Bleed-off Flow, Seal Cooler 1 Inlet Pressure, and Seal Cooler 1 Inlet Temperature.

Results

SmartSignal installed the reactor coolant pump seal models on all 12 reactor coolant pumps at Palo Verde. The models accurately estimated the values for the process variables. However, in two out of twelve pumps, the seal models showed signs of statistically significant residuals. The first case on Pump 1B in Unit 3 represented a seal degradation that plant engineers had already identified. The second case on Pump 1B in Unit 2 demonstrated a similar seal degradation at such an early stage that plant engineers had not yet identified the problem.

Case 1: Unit 3 Pump 1B

SmartSignal eCM models detected degradation of Unit 3 reactor coolant pump 1B first stage seal. The Palo Verde engineers had detected this degradation before the eCM software was installed, and had planned a replacement during the upcoming refueling outage. Since the reactor coolant pump seal package has three seal stages, some degradation of one stage does not compromise the integrity of the overall seal package. The agreement between the eCM model results and the plant engineering analysis confirms the model’s seal degradation detection capability.

Figure 2A shows how the second stage seal pressure (RCP162, Seal Cooler 2 Inlet Pressure) increased over the course of three months. Figure 2A shows the actual value (blue) plotted with the estimated value (green). Figure 2D shows the residual value for the same second stage seal pressure (RCP162). The residual increases because the difference between the actual signal and the eCM estimate increases. The second stage seal pressure residual of 100 psi clearly indicates a seal degradation. The remaining charts in Figure 2 display the two key independent variables- Reactor Coolant Pump Discharge Pressure (RCP190A in Figure 2B and 2E) and the High Pressure Cooler Outlet Temperature (RCT161 in 2C and 2F)- over the same time period.

Case 2: Unit 2 Pump 1B

The SmartSignal eCM models also detected early signs of reactor coolant pump seal degradation on Unit 2 pump 1B. The plant personnel had not yet identiifed this seal problem prior to eCM implementation because the seal outlet pressure appeared to be within the normal variance of the system. Alerts in Figure 3A and 3D show SmartSignal eCM early warning of the deviation in the second stage seal pressure (RCP162, Seal Cooler 2 Inlet Pressure). The actual pressure exceeded the estimated pressure by only 5 psi. The figures also show how the problem advanced over a six month period. Engineers from both SmartSignal and Palo Verde started to carefully monitor this model for further evidence of seal degradation.

Approximately two months after the eCM system first indicated deviations, the conventional plant monitoring system confirmed Pump 1B seal degradation as the second stage seal pressure deviations had increased to the 10-15 psi range. This confirms that SmartSignal eCM provided early warning of reactor coolant pump seal degradation. The plant personnel feel confident that SmartSignal eCM detects early signs of seal degradation when the seal pressure deviates from the expected value by only 5 psi rather than 10-15 psi, providing as much as 2 months early warning. This early warning could allow the plant to avoid additional expenditures associated with expedited emergency repairs.

Conclusion

The SmartSignal eCM technology is a powerful tool for monitoring the condition of reactor coolant pump seals. Experience at Palo Verde proves that SmartSignal eCM can detect statistically significant deviations in pump seal pressure in the 5 psi range that indicate incipient signs of seal degradation, where conventional techniques require at least 10-15 psi deviations. The high sensitivity of this technology provides as much as two months early warning compared to conventional methods. Early warning is key to improve scheduling and reduce maintenance expenditures, providing tremendous value to nuclear power plants.

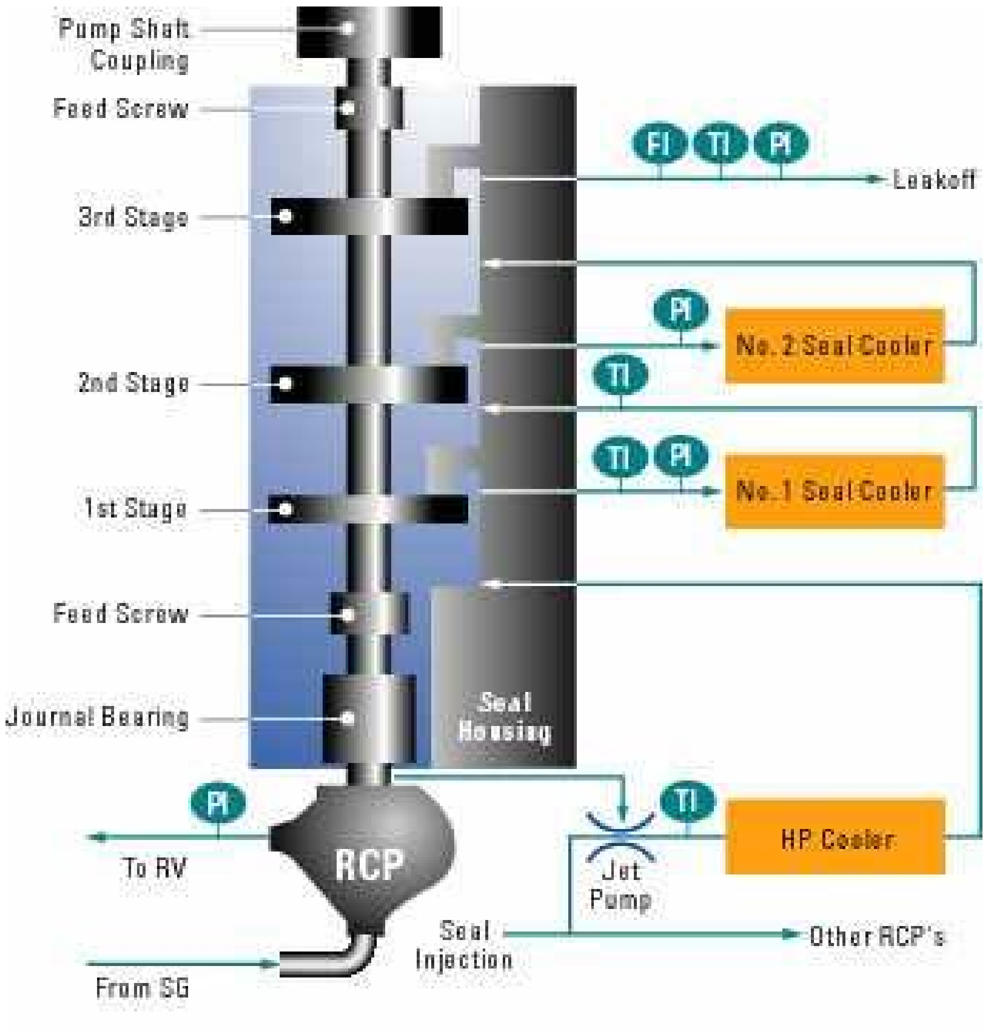


Figure 1. Reactor Coolant Pump Shaft Seal Assembly. Seal cooling water leaves the high pressure cooler, enters the first stage seal housing, passes through seal cooler 1, enters the second stage seal housing, passes through seal cooler 2, then exits as controlled bleed-off flow. Note the positions of pressure, temperature, and flow indicators.

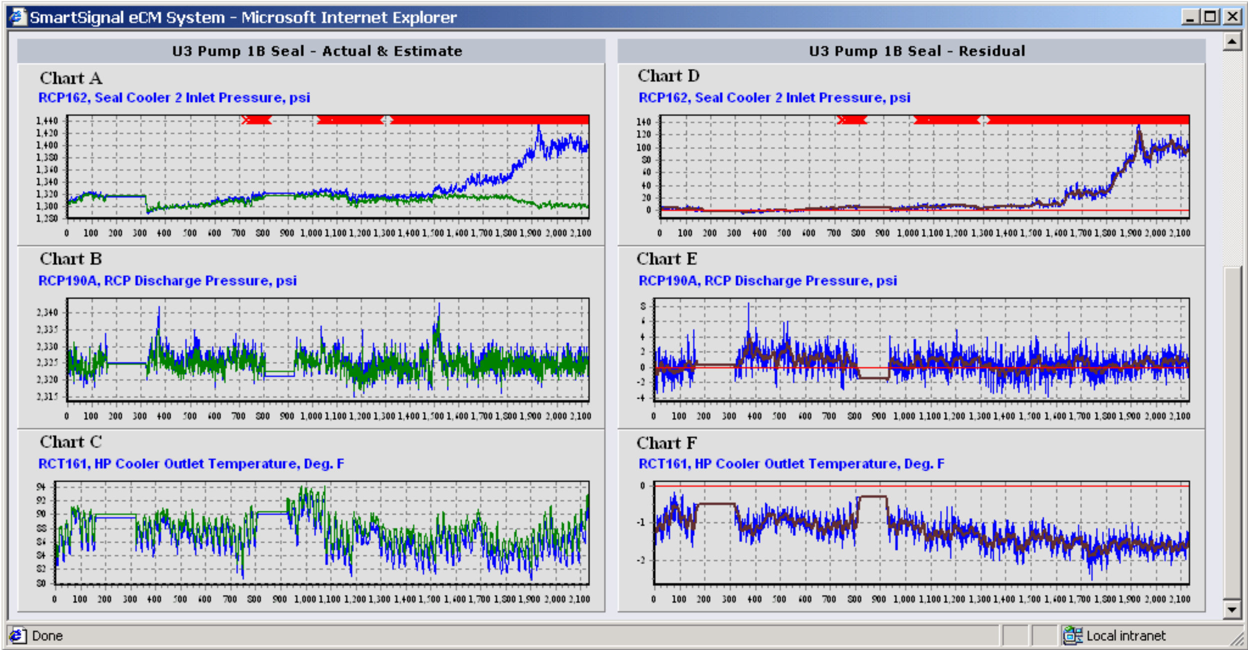


Figure 2. SmartSignal eCM results for key Unit 3 Pump 1B variables for the period 10/5/02 to 1/05/03. Chart A: RCP162, Seal Cooler 2 Inlet Pressure, Actual (blue line) and Estimate (green line), in psig. Chart B: RCP190A, RCP Discharge Pressure, Actual (blue), Estimate (green), Alerts (red X), psi. Chart C: RCT161 HP Cooler Outlet Temperature, Actual (blue) and Estimate (green), DegF. Chart D: RCP162, Seal Cooler 2 Inlet Pressure, Residual (blue) and Smoothed Residual (brown), psig. Chart E: RCP190A, RCP Discharge Pressure, Residual (blue) and Smoothed Residual (brown), psi. Chart F: RCT161 HP Cooler Outlet Temperature, Residual (blue) and Smoothed Residual (brown), DegF.

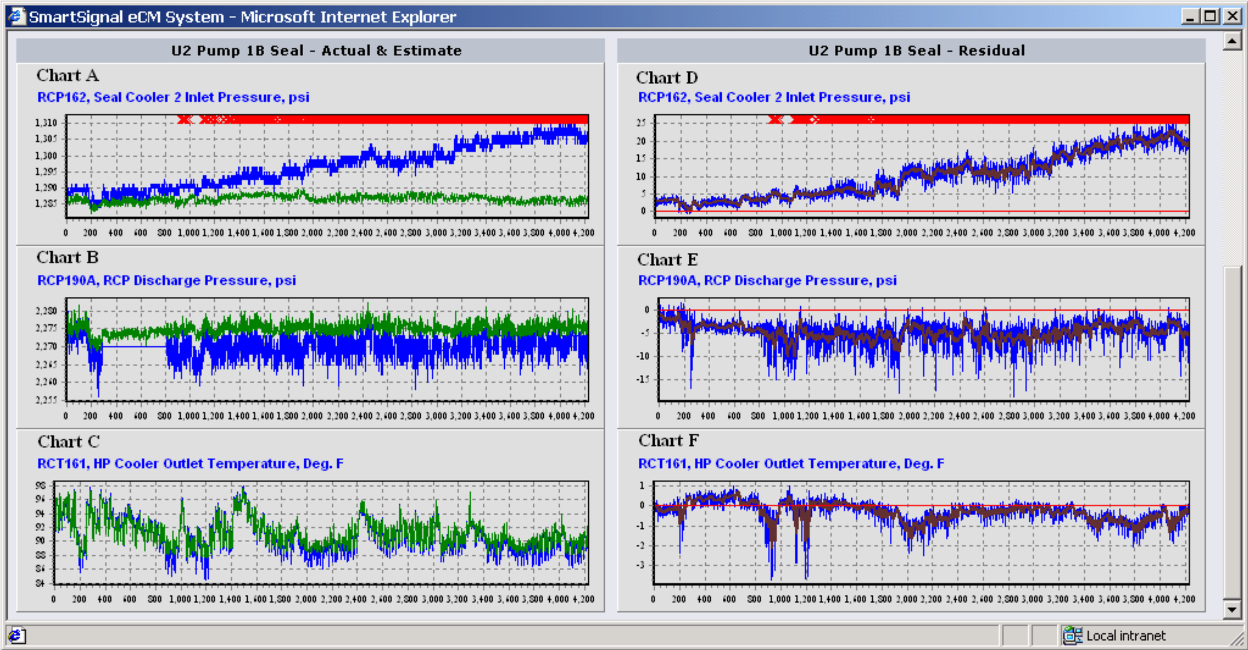
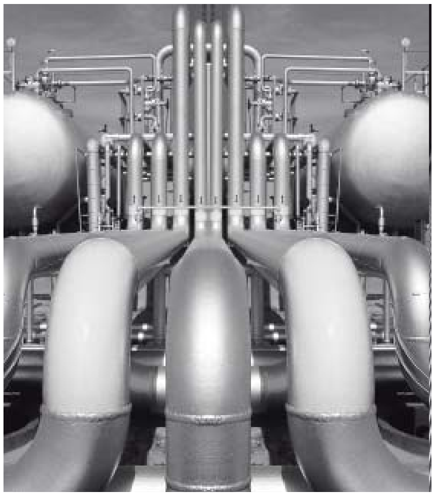
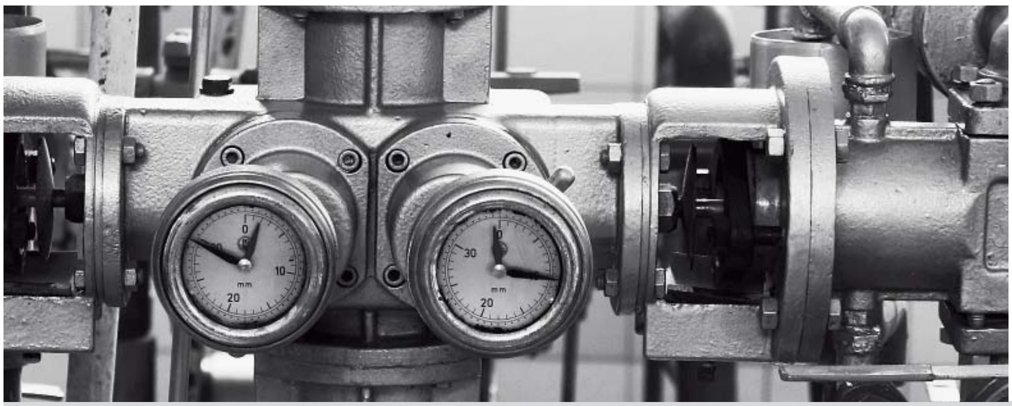


Figure 3. SmartSignal eCM results for key Unit 2 Pump 1B variables for the period 9/25/02 to 3/25/03. Chart A: RCP162, Seal Cooler 2 Inlet Pressure, Actual (blue line), Estimate (green line), Alerts (red X), in psig. Chart B: RCP190A, RCP Discharge Pressure, Actual (blue) and Estimate (green), psi. Chart C: RCT161 HP Cooler Outlet Temperature, Actual (blue) and Estimate (green), DegF. Chart D: RCP162, Seal Cooler 2 Inlet Pressure, Residual (blue) and Smoothed Residual (brown), psig. Chart E: RCP190A, RCP Discharge Pressure, Residual (blue) and Smoothed Residual (brown), psi. Chart F: RCT161 HP Cooler Outlet Temperature, Residual (blue) and Smoothed Residual (brown), DegF.

Tag Name	Tag Description	First stage Seal Degradation	Second Stage Seal Degradation	Third Stage Seal Degradation
RCF166	Controlled Bleed-off flow	+	+	+
RCP163	Controlled Bleed-off Pressure			+
RCT128P	Controlled Bleed-off Temperature			
RCP161	Seal Cooler 1 Inlet Pressure	+		
RCT167	Seal Cooler 1 Inlet Temperature	+		
RCP162	Seal Cooler 2 Inlet Pressure		+	
RCT191	Seal Cooler 2 Inlet Temperature			
RCP190A	RCP Discharge Pressure			
RCT160	HP Cooler Inlet Temperature			
RCT161	HP Cooler Outlet Temperature			
RCT166P	RCP Upper Thrust Bearing Temp			

Table 1. List of Process Variables and Fingerprint Chart for the RCP Seal Model. Tag names, description, list of fault type, and deviation signature. The first column lists the process variables and the first row shows fault type. The table indicates a fault signature as process variables deviate from expected value in the high (+) or low (-) direction depending on fault type.





ABOUT SMARTSIGNAL

SmartSignal maximizes worldwide industry equipment performance, availability, and reliability by detecting, diagnosing, and prioritizing equipment and process problems before they become costly failures. Drawing on over 40 patents, SmartSignal delivers specific, relevant, and actionable intelligence that makes people more proactive and productive. SmartSignal serves customers in power generation, oil and gas, mining, aviation, pulp and paper, and other process industries worldwide. SmartSignal and its customers have won over twenty awards for excellence, including the *Wall Street Journal* Technology Innovation Award.

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