Monitoring and Analyzing Generator Displacements to Understand Alignment Problems

by

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Introduction

Detailed data analysis is an important component for obtaining the full potential of an on-line monitoring system. Although monitoring systems are typically designed to automatically trigger alarms and to easily view trends of the data, more detailed analyses are often required. For example, upon initial installation of a monitoring system, a detailed review of the data is required to ensure that alarm limits are set at proper values and that the dead bands for archival data are appropriate. Once a monitoring system is operating, detailed data analyses and additional instrumentation may be required whenever problems are detected.

This paper discusses the implementation of a generator monitoring system on a hydro unit at the Public Utility District No. 1 of Chelan County (CCPUD). A monitoring system was initially installed to determine the root cause of recurring generator alignment problems, with the ultimate objective of producing alarms for detecting abnormal operating states. The generator monitoring system consisted of four capacitive sensors to measure the rotating stator-to-rotor air gap. After generator alignment problems were detected, CCPUD installed additional instrumentation including: 42 proximity probes to measure displacements of non rotating components; 12 temperature measurements for evaluating temperature transients; and multiple channels of unit operating information. This instrumentation created a comprehensive volume of data, but these data were contained in three separate data bases.

Although the instrumentation set was extensive, determining the probable root cause of the generator misalignment was difficult because the answer was literally buried in a very large and disjointed data set. Analyzing the data was further complicated due to the large transients in the data that occurred as a result of unit startup and shutdown. Troubleshooting the root causes for the generator misalignment required several different data analysis techniques that included: (1) synchronizing the disparate data sets; (2) filtering the data to reduce thermal and startup transients; and (3) correlating patterns in the data to pinpoint the components producing the misalignment. Due to sheer volume of data, it was important to streamline these tasks. This paper discusses the instrumentation, data, and data analysis techniques used to determine the probable root cause of the generator misalignment.

Background

CCPUD initiated a comprehensive generator monitoring program at its Rock Island Hydroelectric Project to enhance generator reliability and to determine the health of the units. This was initiated when generator failures at CCPUD’s Rocky Reach Hydroelectric Project led to lengthy forced outages.

Initially, VibroSystM air gap monitoring systems were installed on four units. The measurements recorded by the systems indicated that the air gap displacements were well below industry standards and that the displacements gradually drifted over time. In an effort to understand the root cause of the problem, a second instrumentation system was installed. This system consisted of proximity probes and thermocouples to measure the displacements and temperatures of stationary components. Unit operating information, including power output, blade, gate, headwater, and tailwater readings, were also available in a PI data base. The data analyzed in this paper were acquired over a time period of approximately one year. A more detailed description of each of the instrumentation systems and the data analysis procedures is presented below.

VibroSystM AGMS - The VibroSystM Air Gap Monitoring System (AGMS) was used to measure the gap between the stator and the rotor. The sensors for this system consist of four capacitive probes mounted at 90 degree intervals around the circumference of the stator. The AGMS system samples the displacement at 6,000 Hz for one of the sensors and at 750 Hz for the three remaining sensors. With a generator rotational speed of 100 rpm, a minimum of approximately 500 samples per revolution are acquired from each sensor. The data presented in this paper are the minimum displacement readings acquired from each of the four sensors over five minute intervals.

Stationary Displacement Data - Proximity probes were installed to measure the relative displacements of primary generator components. The components of the generator that were instrumented included the stator frame at the soleplates, the stator core, the generator guide bearing retaining ring, and the lower generator bracket. Displacements were measured at 42 different points, and the data included both displacements relative to ground and displacements relative to other generator components.

An Omega Engineering MultiScan 1200 data logger and a personal computer were used to acquire the data analyzed from these instruments. Although data were sampled at various frequencies over the course of a several month period, it was determined that a 20 minute sampling interval was sufficient to characterize the displacement of the stationary components.

Temperature Data - Temperatures of the generator lower bracket were measured at 12 different points in addition to the ambient temperature in the turbine wheel pit. These data were logged by the same MultiScan data logger and at the same frequency as the stationary displacement data.

Unit Operating Data – The unit operating data was obtained from CCPUD's OSIsoft™ PI archival data base over the same time period as the VibroSystM data, at five minute sampling intervals. The operating data included time, power, flow, wicket gate opening, blade angle, generator operating parameters, and unit temperature measurements.

Data Analysis Procedures

Because the instrumentation systems were in the initial demonstration phase during these tests, the data were not fully integrated into a centralized data base. As a result, the data presented in this paper were initially contained in approximately sixty different files and in three different formats. Manual processing of this data would have required a prohibitive amount of time. Therefore, automating the data processing was a key part of this project.

DataWolff™, an Excel-based data analysis program, was used to automate the data processing. DataWolff is a general data analysis and automation engine for Microsoft Excel that is configured for a specific analysis by using a specific data analysis script. Figure 1 presents a schematic of the key data processing steps required for this project. The data import template specifies which data to import and filters out bad readings. The calculation template configures DataWolff to decimate the data; to synchronize the disparate data sets, providing consistent time stamps and row-by-row consistency in Excel; and to filter out the large startup transients which obscured key patterns in the trends. The chart template, in conjunction with the chart library, was configured to create trends of all data in Excel charts that enabled the user to zoom-in, zoom-out, and scroll in time through the data.

Figure 2 presents a flow chart of the automated data processing achieved using DataWolff. The analysis script configures DataWolff to process data in a batch mode. Once the analysis script is loaded, a user is prompted to select the files for analysis. The analysis then proceeds automatically and produces an Excel workbook containing the desired calculations and results.

Results

Determining probable root causes for the generator alignment problems required an iterative approach that consisted of several cycles of viewing the data in different groupings and using different filtering techniques. However, for the sake of clarity in presenting the analyses for this paper, the data analysis process is best described by discussing the VibroSystM data first and then correlating patterns in these data to those observed in the stationary displacement data.

VibroSystM Results - Figures 3 through 5 present air gap data obtained from the four VibroSystM sensors. Figure 3 presents data acquired in the time period from 1/10/2003 through 12/31/2003. A step change in the data occurs in August of 2003, corresponding to a unit realignment. Other trends are obscured by the short term variations in the displacement that occur.

Figure 4 displays a magnified view of the data obtained over a three day interval in the beginning of June 2003. The unit generation is also shown in Figure 4. This figure demonstrates that there is a transient period shortly after unit startup during which the minimum air gap is continuously increasing. Once steady state operation is achieved, there is little variation in the minimum air gap value.

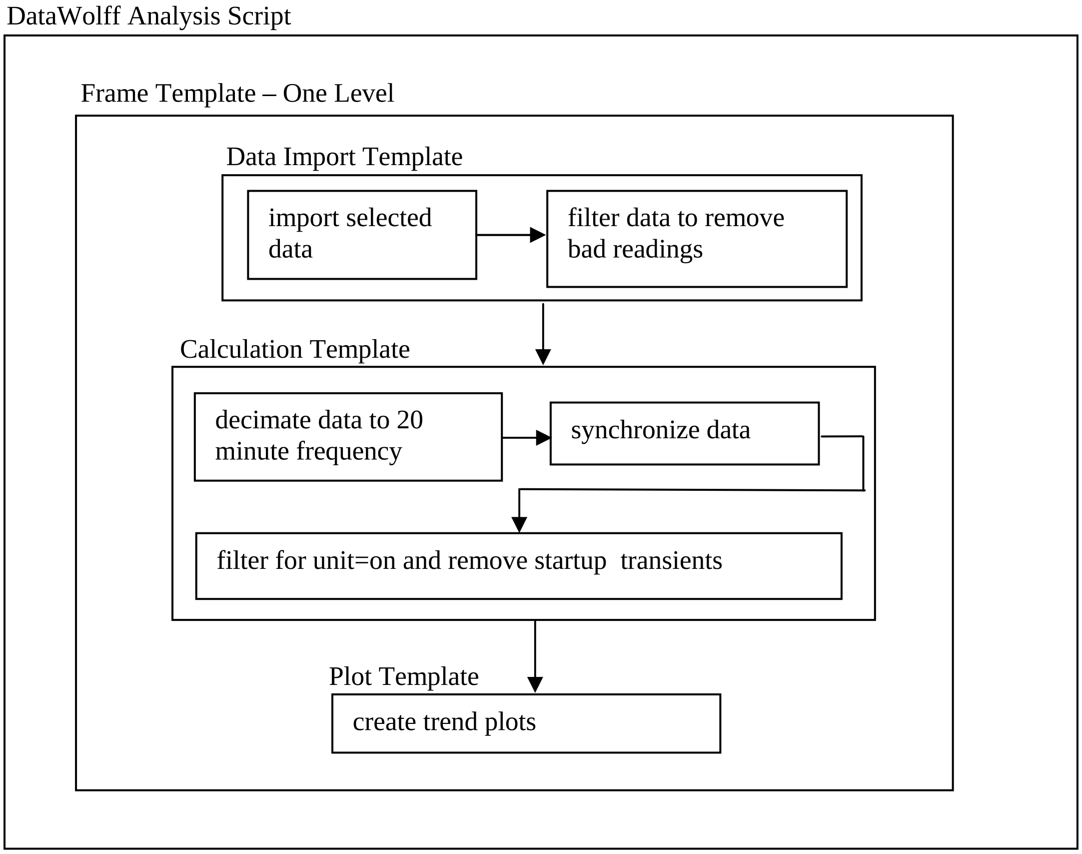

Figure 1: Data Analysis Steps

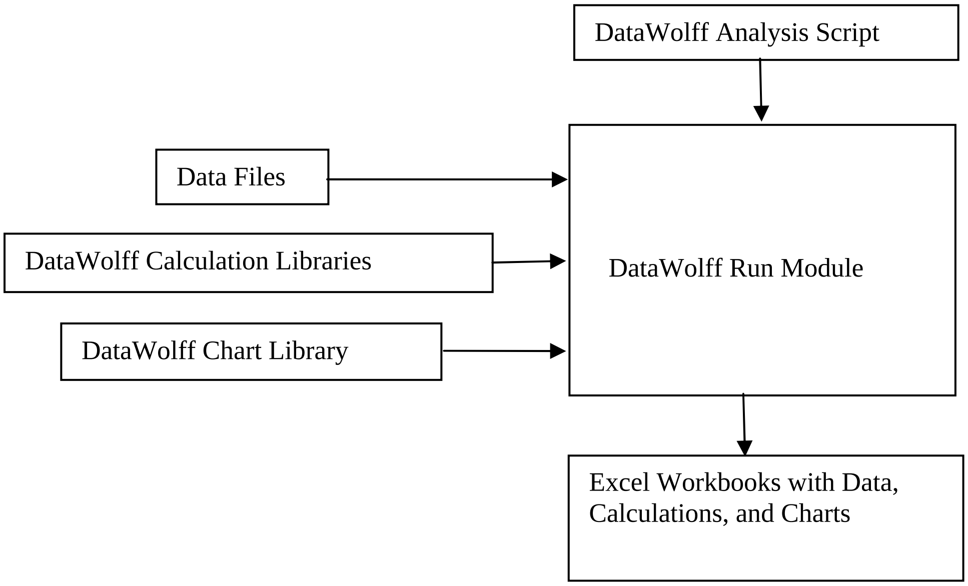

Figure 2: Schematic Illustrating Streamlined Data Processing

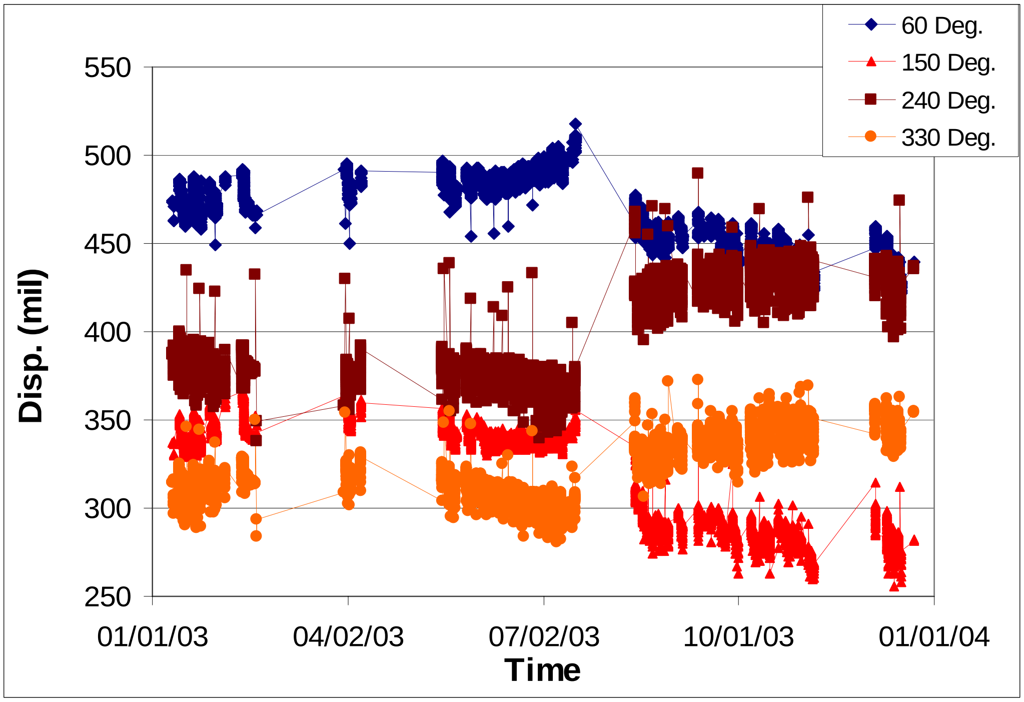

Figure 3: VibroSystM Data

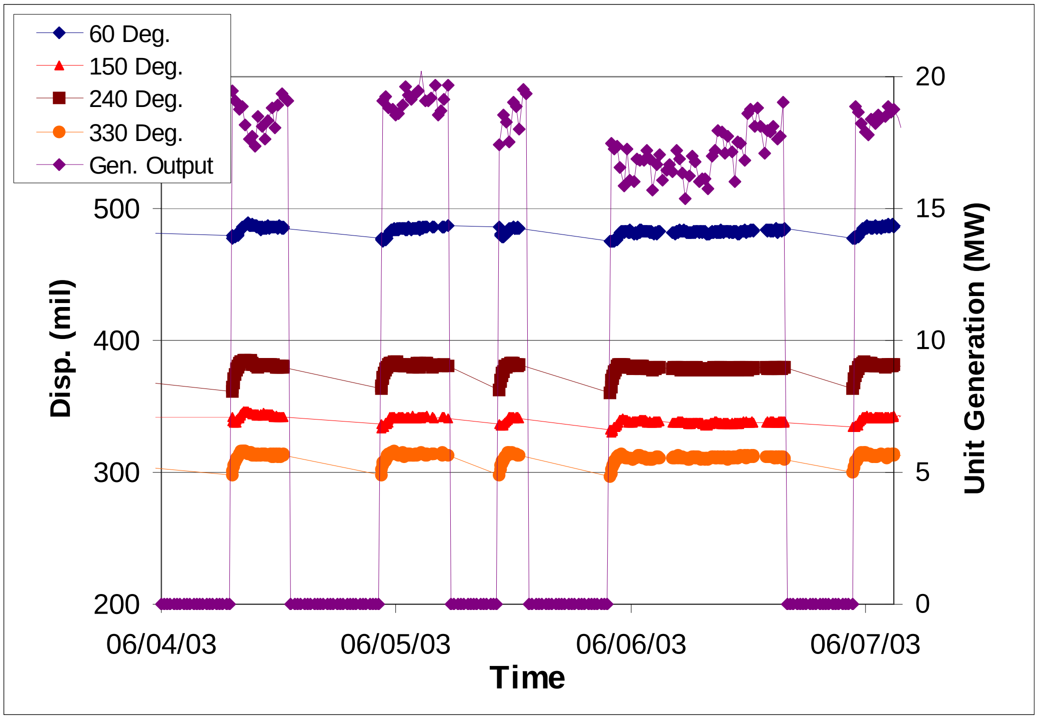

Figure 4: Magnified VibroSystM Data with Unit Power

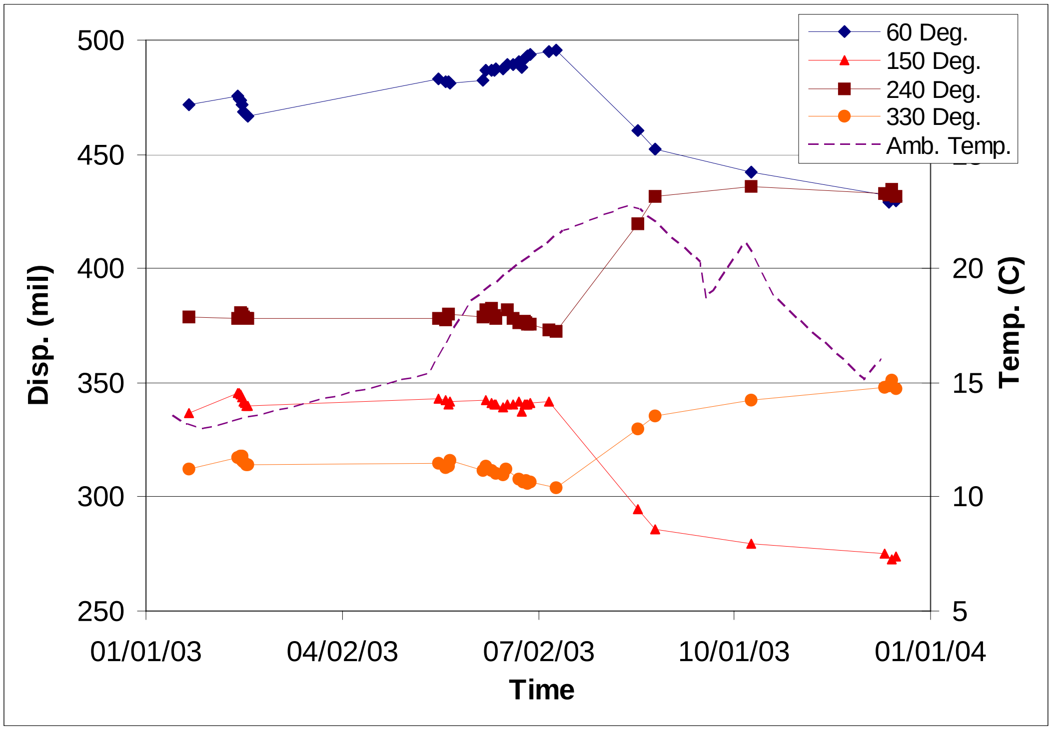

Figure 5: Filtered VibroSystM Data

Figure 5 presents both the filtered VibroSystM data and the ambient temperature. The filtering removed the startup transients, thereby reducing much of the noise in the data. Long term trends can be observed in all sensors, but the trends are most apparent in the data for the sensors mounted at 60 and 330 degrees. For example, the air gap at 60 degrees gradually increases over the time period from mid-February 2003 until mid-July 2003. A step change in the air gap occurs, corresponding to the time when the unit was realigned. The air gap then gradually decreases for the time period from the end of August 2003 until mid-December 2003, when the data set ends. These trends in data correspond closely to the trends in the temperature data (i.e., as the ambient temperature increases, the air gap increases and decreasing air ambient temperatures corresponds to a decreasing air gap). The air gap at 330 degrees displays an opposite trend: as the ambient temperature increases, the air gap decreases, and as the ambient temperature decreases, the air gap increases.

<u>Stationary Displacement and Temperature Data</u> – Figure 6 presents all of the temperatures for the various generator components that were acquired by the MultiScan system. All of the temperatures display a long term trend that follows the ambient temperature trend with short term temperature spikes. Figure 7 displays the typical temperature transient that occurs for the generator components as the unit cycles on and off. While the unit is running, the temperature increases. Once the unit is shut down, the temperature asymptotically decays towards a steady state temperature. Figure 8 provides all of the displacements acquired with the MultiScan system. The displacements exhibit spikes, similar to the temperatures shown in Figure 6.

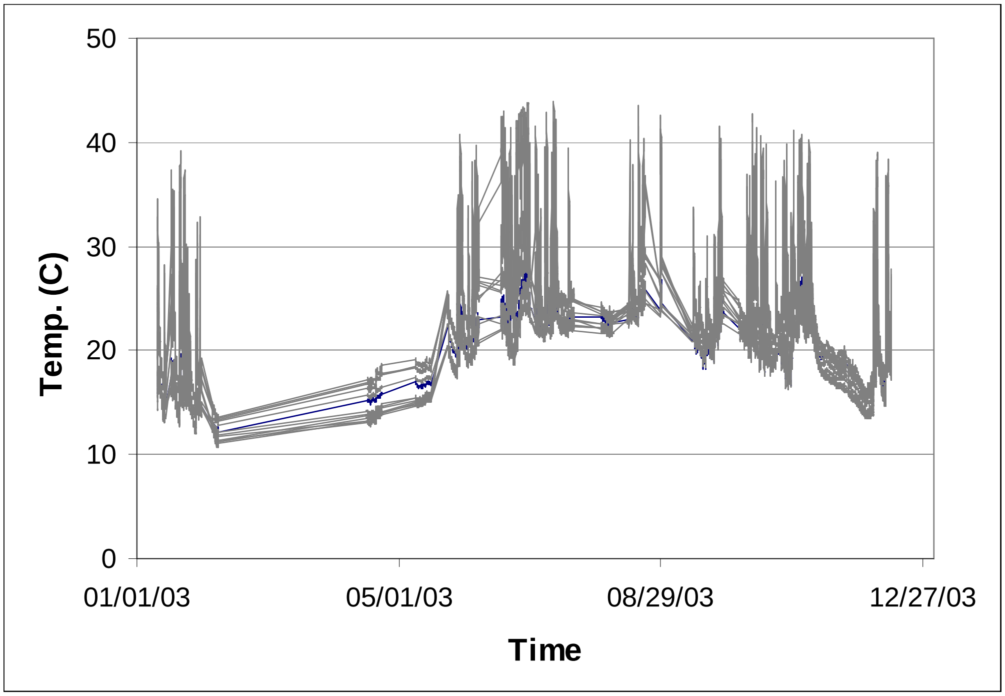

Figure 6: Generator Temperature Data

Figure 9 presents a plot showing a typical displacement signal as the unit cycles on and off. The short term displacement behaves in a manner similar to the component temperature, which is most likely caused by thermal expansion of the various generator components.

Figure 10 presents the filtered displacements ULB-NS1 through ULB-NS4. The filtered displacements represent the generator displacements after the unit is shut down and after sufficient time has elapsed to ensure that the displacements have reached their asymptotic limits. Displacements ULB-NS1 through ULB-NS4 represent axial displacements of the upper-lower generator bracket in a direction that lies parallel to the axis of the dam (north-south direction). Transducers ULB-NS1 and ULB-NS4 are on the north side of the bracket while transducers ULB-NS2 and ULB-NS3 lie directly opposite on the south side of the bracket. Long term trends in the axial displacements of the upper-lower generator bracket are very similar to the ambient temperature cycle. The displacement of the upper-lower generator bracket is particularly important for generator alignment because it houses the lower generator guide bearing.

Figure 11 presents the filtered mid-span displacements of the upper-lower generator bracket in the direction transverse to the direction in which this bracket lies. The transducers ULB-UTP and ULB-UBT are located on the upstream side of the generator and measure displacements perpendicular to the transducers ULB-NS1 through ULB-NS4. The transducers ULB-DTP and ULB-DBT are located on the downstream side of the generator, opposite to ULB-UTP and ULB-UBT. Figure 11 demonstrates that transverse displacements of the bracket change as the ambient temperature changes. This is especially apparent for a few months beginning in August 2003, when the average ambient temperature decreases from its peak value. The sensors on opposite sides of the bracket change as the ambient temperature decreases.

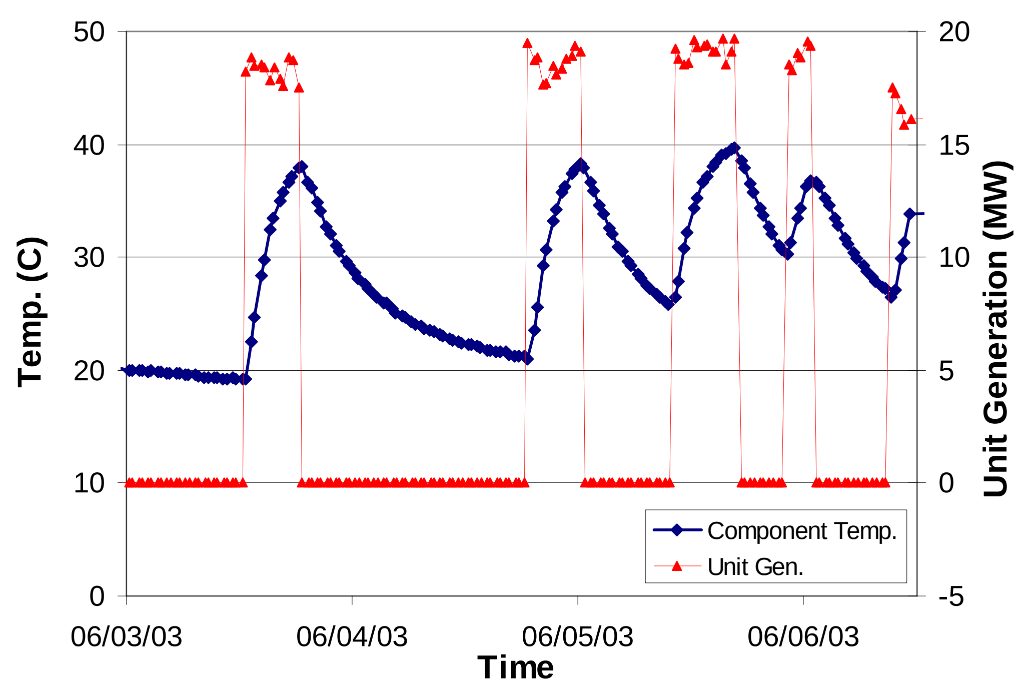

Figure 7: Typical Temperature Cycling of a Generator Component

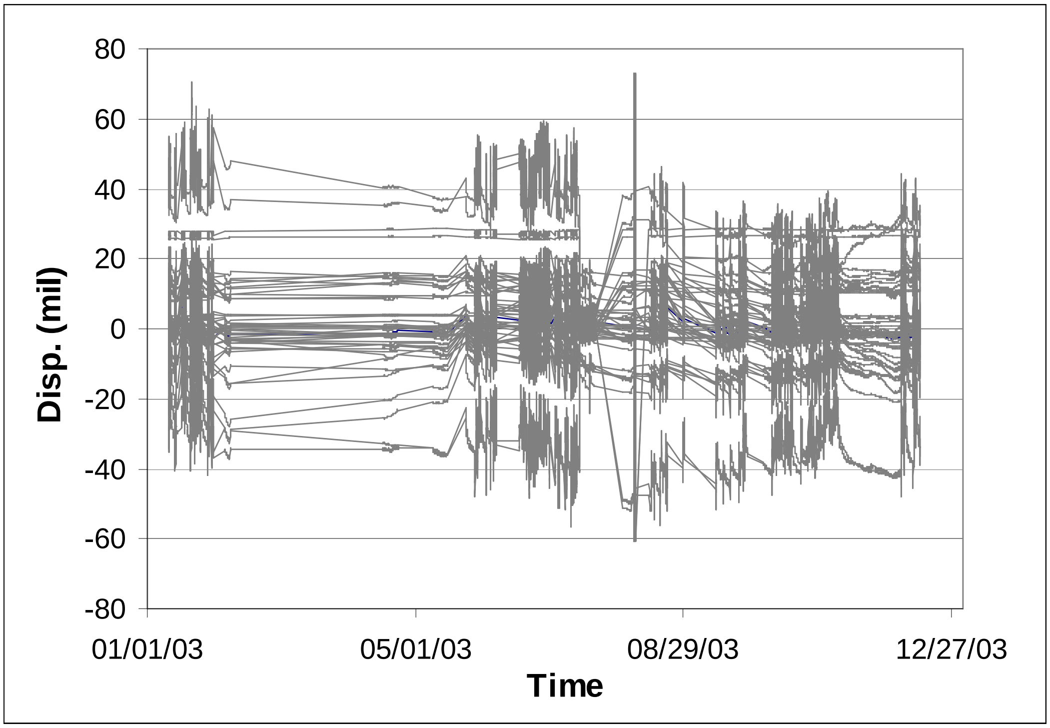

Figure 8: Generator Displacement Data

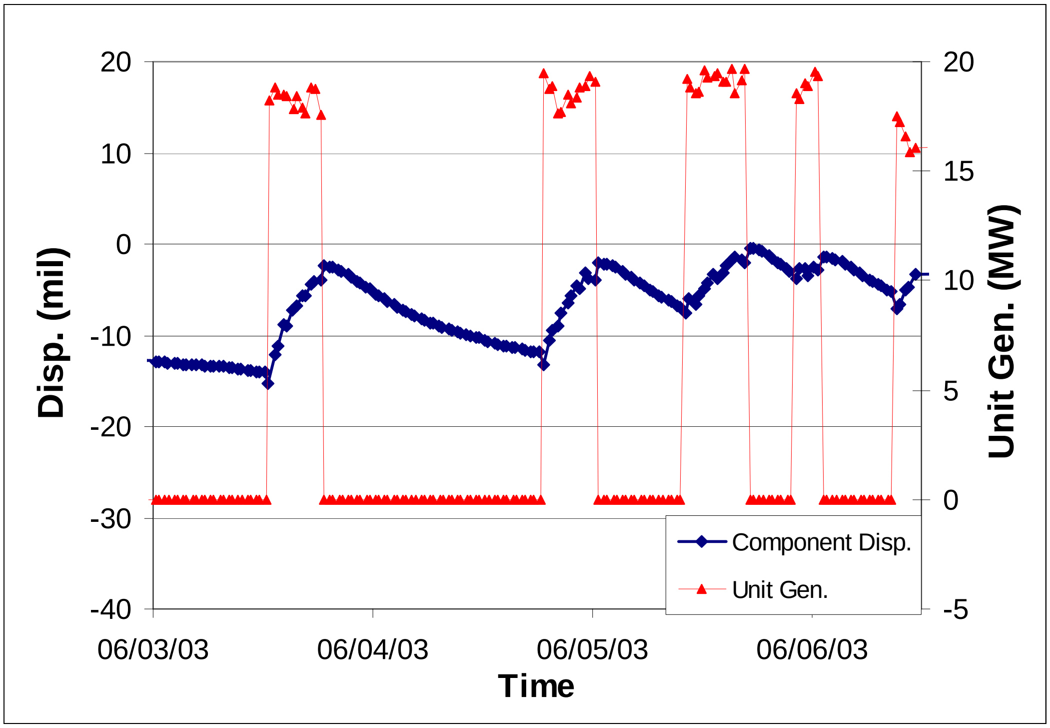

Figure 9: Typical Cycles for Displacements of a Generator Component

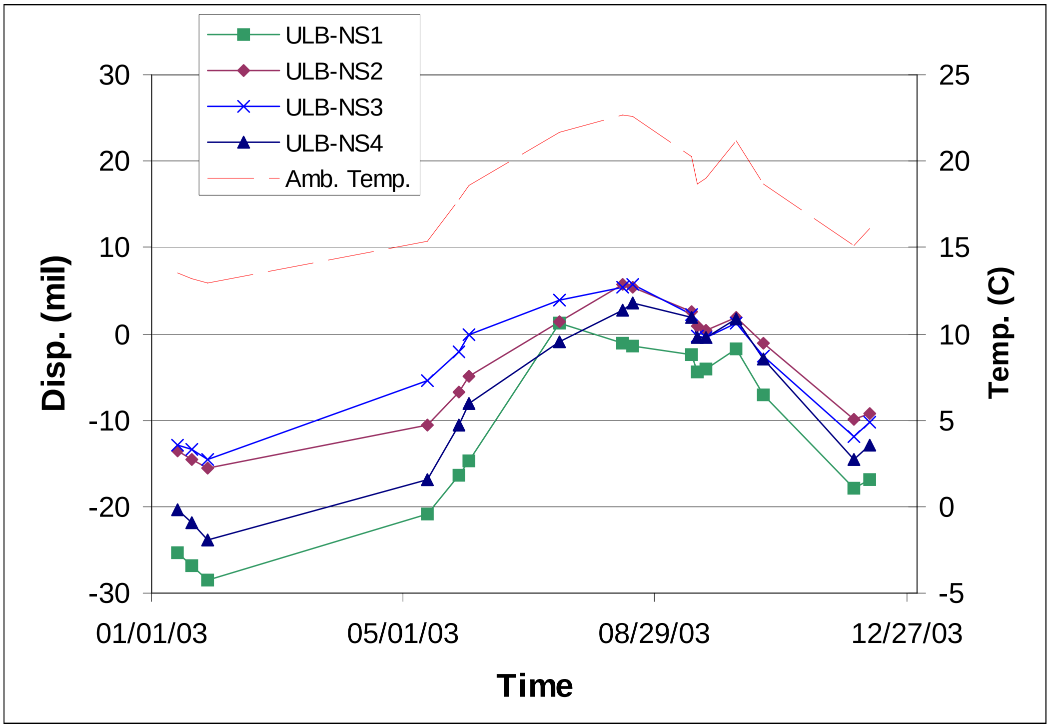

Figure 10: Filtered Axial Displacements of Upper-Lower Generator Bracket

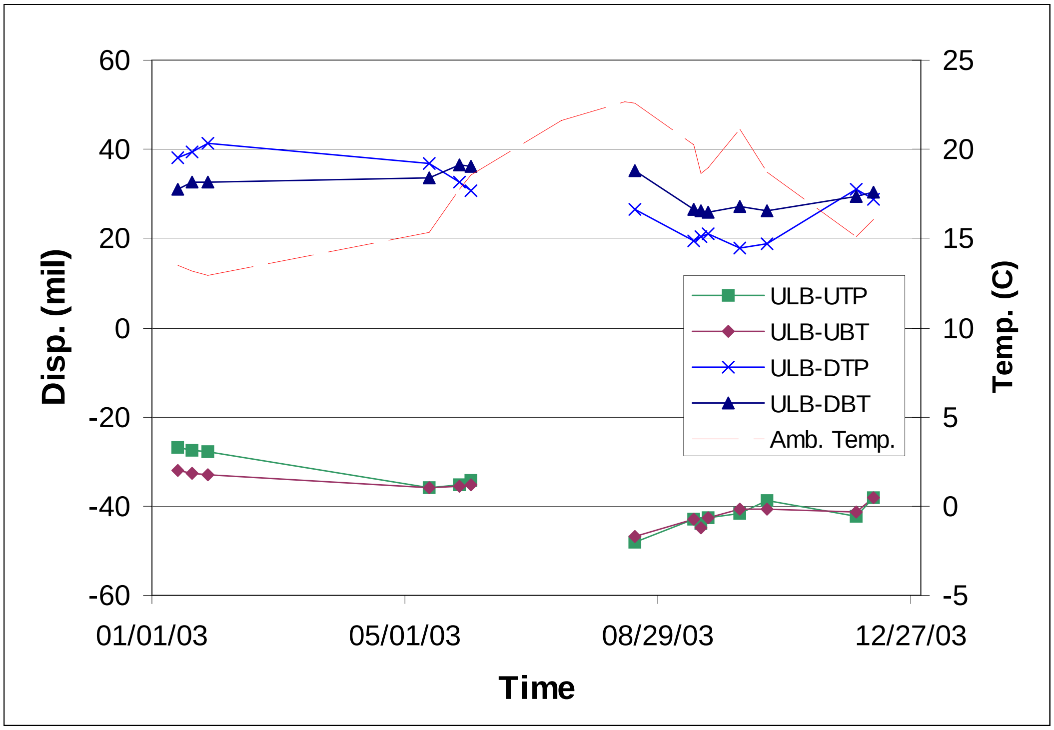

Figure 11: Filtered Transverse Displacements of Upper-Lower Generator Bracket

Discussion of Results

The analyses performed for this study indicate that the stator-to-rotor generator air gap is strongly dependent on the ambient temperature. Axial displacements of the upper-lower generator bracket also change with ambient temperature. The displacements of this component are particularly relevant to generator alignment because it houses the generator guide and thrust bearings.

The axial displacements of the upper-lower generator bracket are in phase with the ambient temperature cycles (i.e., they increase with increasing ambient temperature and decrease with decreasing temperature). The displacements are measured with proximity probes attached on steel mounting brackets, which in turn are rigidly attached to concrete in the turbine wheel pit. A possible cause for the axial displacements of the upper-lower bracket could be the forces produced by the four bolts that anchor each lower-lower generator bracket to the turbine wheel pit, along the length of the lower-lower bracket. Thermal expansion of the bolts, or thermal expansion of the turbine wheel pit, could cause the lower-lower bracket to displace transversely, which would cause an axial displacement of the upper-lower bracket.

Axial displacements of the upper-lower bracket could produce a compressive force, which would cause the bracket to bend. The bending displacement would appear as a transverse displacement of the mid-span of the upper-lower generator bracket with displacements on opposite sides of the bracket being in opposite phase. This is a possible explanation for the trends seen in Figure 11, which show that the transverse displacements change as the ambient temperature decreases and that the displacements on the upstream side move in a direction opposite to the displacements on the downstream side.

Conclusions and Recommendations

This paper presents an overview of a generator monitoring system and describes the data analysis procedures that were used to troubleshoot the root cause of generator misalignment. CCPUD installed a comprehensive set of instrumentation to measure both the air gap displacement and stationary displacements of several generator components. After complex processing of the data, the long term trends in the data became apparent. By correlating the long term patterns in the air gap displacements to long term patterns in the stationary sensors, the probable cause for the unit misalignment was determined.

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