FATIGUE ANALYSIS THROUGH AUTOMATED CYCLE COUNTING USING ThermAND

Gordon R. BURTON[1], Yuqing DING[1], A. SCOVIL[2], and M. YETISIR[1]

ABSTRACT

The potential for fatigue damage due to thermal transients is one of the degradation mechanisms that needs to be managed for plant components. The original design of CANDU® stations accounts for projected fatigue usage for specific components over a specified design lifetime. Fatigue design calculations were based on estimates of the number and severity of expected transients for 30 years operation at 80% power. Many CANDU plants are now approaching the end of their design lives and are being considered for extended operation. Industry practice is to have a comprehensive fatigue management program in place for extended operation beyond the original design life. A CANDU-specific framework for fatigue management has recently been developed to identify the options for implementation, and the critical components and locations requiring long-term fatigue monitoring.

An essential element of fatigue monitoring is to identify, count and monitor the number of plant transients to ensure that the number assumed in the original design is not exceeded. The number and severity of actual CANDU station thermal transients at key locations in critical systems have been assessed using ThermAND™, AECL's health monitor for systems and components, based on archived station operational data. The automated cycle counting has demonstrated that actual transients are generally less numerous than the quantity assumed in the design basis, and are almost always significantly less severe.

This paper will discuss the methodology to adapt ThermAND for automated cycle counting of specific system transients, illustrate and test this capability for cycle-based fatigue monitoring using CANDU station data, report the results, and provide data for stress-based fatigue calculations.

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1 INTRODUCTION

The potential for fatigue degradation of metal components has been recognized as a key issue when assessing the aging of plant components [1]. Fatigue issues are considered during the design of CANDU® nuclear generating stations by including calculations of projected fatigue usage for specific components. These cumulative fatigue calculations are based on estimates of the number and severity of expected transients for 30 years operation at 80% power (equivalent to 24 effective full power years (EFPY) of operation). Many CANDU plants are now approaching their design end-of-life and are being considered for extended operation beyond their design life. Nuclear regulatory agencies are concerned about the fatigue life of components in extended-life operation. In the United States (US), the US Nuclear Regulatory Commission (NRC) requires nuclear generating stations to have comprehensive component fatigue management programs for their license renewal applications for extended operation [2].

The severity of actual station transients has been assessed previously by extracting station data and identifying transients manually. The work identified that actual transients are generally less numerous than the quantity assumed in the design basis, and are almost always significantly less severe. These preliminary findings indicated the importance of classification and counting of actual transients as an essential element of the fatigue management program for plants pursuing Plant Life Extension (PLEX).

The aim of the present work is to report on the development of a fatigue-monitoring routine to automate the counting and classification of thermal transients for critical systems at key locations, identified in collaboration with station staff, and calculate the severity of identified transients (e.g., compare calculated rate of change of temperature with that used in design) based on CANDU station data. The routine will permit the user to identify those transients that are of importance. The results can be used to calculate cumulative fatigue usage factors based on actual station transients.

For the majority of cases, cycle counting as incorporated into ThermAND™ is sufficient to assess the fatigue usage in the system. ThermAND, AECL's health monitoring software for systems and components, was developed on field trial at Point Lepreau Generating Station (PLGS) and is now in commercial use [3]. The software has access to many years of historical plant data, and provides system specialists with the ability to display, analyze, model and receive alarms and warnings on key station parameters. In those cases where the cumulative fatigue usage is higher

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and warrants further analysis, the ThermAND software can be used to export the required station data for input into other assessments using generic, commercially available software, e.g., using FatiguePro.

2 CYCLE COUNTING USING THERMAND

2.1 Definition of Plant States and Transients

The objective of ThermAND is to provide monitoring and diagnostic functionality to help manage the health of all major heat transport circuits at the plant, not just the primary heat transport system. Health monitoring includes both performance and condition monitoring of the interconnecting piping and of major components within each system, such as pumps, vessels, and heat exchangers [3].

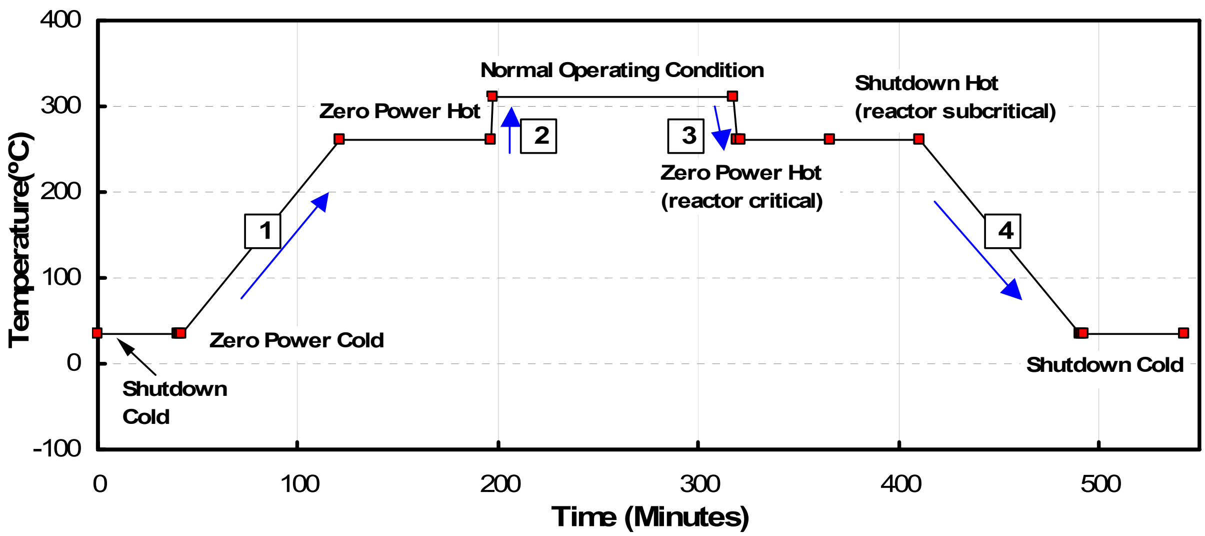

Figure 1: Definition of Typical Plant Operating States

The fatigue-monitoring module being developed at AECL uses the functionality developed in ThermAND to automate the counting of thermal transients for specific locations. The initial design of the module in ThermAND permits the user to define rules for transient classification and counting. The transients related to normal reactor operation (excluding Power Maneuvering transients) and Reactor Trip transients counted and classified in the present work are given in Table 1, and shown graphically in Figure 1 as represented by the primary coolant temperature. It can be seen in the example in Figure 1 that the reactor is initially cold and sub-critical in the 'Shutdown Cold' state. As the reactor achieves criticality it passes to 'Zero Power Cold' and when warmed up enters the 'Zero Power Hot' state. Raising the reactor power for start-up brings the reactor into 'Normal Operating Condition'. When the reactor is shutdown, the reactor power is lowered to bring the plant to 'Zero Power Hot', the reactor goes sub-critical passing to the 'Shutdown Hot' state, then the plant is cooled down to achieve the 'Shutdown Cold' state.

Table 1
Plant States and Rules Defined in ThermAND

Plant State	Conditions
Shutdown Cold	(Logarithmic Reactor Power < -4.5) & (PHT Temperature < 100°C)
Zero Power Cold	(Logarithmic Reactor Power ≥ -4.5) & (PHT System Temperature < 100°C)
Zero Power Hot	(Logarithmic Reactor Power ≥ -4.5) & (Reactor Power ≤ 0.02 FP) & (PHT System Temperature > 250°C)
Normal Operating Condition	(Reactor Power > 0.1 FP) & (PHT System Temperature > 250°C)
Shutdown Hot	(Logarithmic Reactor Power < -4.5) & (PHT System Temperature > 250°C)

The monitored station parameters that uniquely identify these states are the logarithmic reactor power (to access criticality at low power levels), the linear reactor power (to monitor the increase in power to full power operation), and the temperature of the primary coolant (to identify when the system is hot). ThermAND permits the user to define plants states and set limits based on parameters that are monitored by the station control computers as given in Table 1. The limits are defined based on a thorough review of the station operating data and discussions with station staff to ensure that the plant states are uniquely and consistently identified.

The requirement for fatigue monitoring is to count the number of transients that a system has encountered during station operation. ThermAND permits the user to define transients from one plant state to another and these transients as shown in Table 2. The number in parentheses refers to the numbered label in Figure 1. The identified transients are the same as those defined for the initial stress and fatigue analysis for major CANDU systems. The aim of cycle counting is to count the number of these and determine the number and severity of each transient, because the original analysis defines the acceptable number of each type of transient.

Table 2
Definitions of Plant Transients in ThermAND

Plant Transient	Transition	
	From Plant State	**To Plant State**
Achieve Criticality Cold	Shutdown Cold	Zero Power Cold
Warmup (1)	Zero Power Cold	Zero Power Hot
Startup (2)	Zero Power Hot	Normal Operating Condition
Shutdown (3)	Normal Operating Condition	Zero Power Hot
Lose Criticality	Zero Power Hot	Shutdown Hot
Cooldown (4)	Shutdown Hot	Shutdown Cold
Trip	Normal Operating Condition	Shutdown Cold

2.2 Visualization of Plant Transients using ThermAND

The assessment of station transients is enhanced by the ability to view station data in ThermAND. ThermAND was used to visualize the plant state as shown in Figure 2, along with the linear and logarithmic reactor power and the reactor outlet header temperature that are used to uniquely identify the plant state. The rules to determine plant state given in Table 1 were programmed in ThermAND and the result is shown in the purple trace in the bottom right of Figure 2. Compare Figure 2 with Figure 1. The vertical scale is chosen such that a number represents each plant state from 1 (for Shutdown Cold) to 9 (for normal operating condition) so that the user can visualize the change in plant state. It is difficult to identify the plant states from the raw station operating data (in blue). It can be seen from the Plant State trace (in purple) that the plant is initially in normal full power operation, when the reactor power is dropped. The reactor is held briefly at zero power hot and then cooled to zero power cold and then shutdown cold. The outage lasted for approximately one day after which time the reactor was made critical again (state changed from shutdown cold to zero power cold), heated up to zero power hot and the power raised to normal operating condition. Transition periods, where the values of the station parameters do not match one of the defined states, account for the gaps observed in the trace.

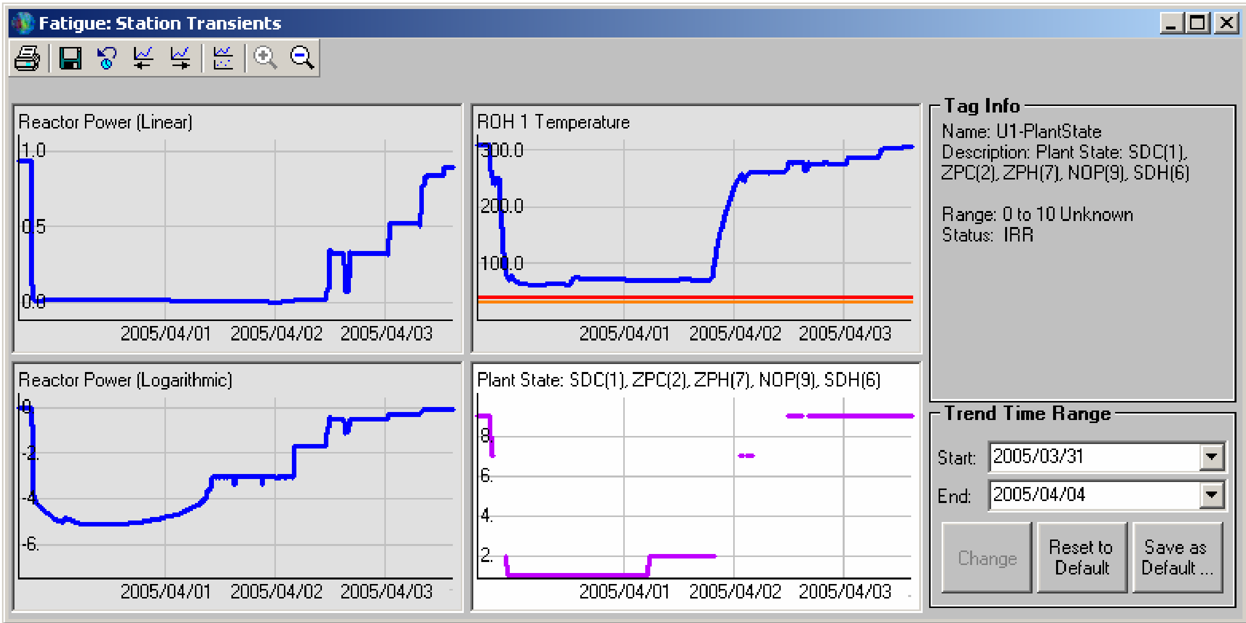

Figure 2: Visualization of Station Transients

3 RESULTS AND DISCUSSIONS

The transients defined based on reactor power and primary coolant temperature counted using ThermAND are summarized in Table 2 and the results of the automated counting of a subset of these for shutdown transients (i.e., from normal operating condition to zero power hot) are given in Table 3. As seen in Table 3, there are 13 shutdowns detected by ThermAND in the assessed time period. The date and time of the shutdown determined automatically by ThermAND from scanning through the data are consistent with, and more accurate than, the plant records entered in station logs after the shutdown event occurred.

The automated process used by ThermAND was able to identify one shutdown in 2005 March/April that was not identified as part of the previous manual assessment and had not been recorded previously in the station database. The automated routine has therefore improved upon the manual process being much faster, scanning through the data in 2 to 3 minutes (for all transients in Table 2), and more thorough at identifying transients. The ThermAND-identified transient start and end times permit the station staff to focus on the data specific to each transient without the need to scan through all the data. There are also six upset transients (Table 3) detected by ThermAND during this period and these have been confirmed with the PLGS Upset Event Database.

It can be concluded from the results in Table 3 for shutdown transients (and for the other transients identified in Table 2, not shown) that the fatigue monitoring module in ThermAND has the capability to automatically classify and count normal transients (shutdown, cooldown, warmup and startup) and provide very useful information for users to track upset transients.

Enhancements to the module are planned to calculate the severity of the transient (e.g., the calculated maximum rate of change of a critical parameter during the transient), to permit the user to go directly to the identified transient in ThermAND, and to calculate the cumulative fatigue usage factor based on the known fatigue usage factor and the number of identified transients of each type. The result will be a complete report of the fatigue usage history over the assessed time period.

Table 3
Shutdown Transients Counted Using ThermAND and Identified from PLGS Plant Data During the Period from 1998/01/01 to 2006/06/15

ThermAND	PLGS Shutdown History[1]	Upset Events[2]
23/05/1998	23/05/1998	
08/05/1999	08/05/1999	
09/03/2000		STEPBACK
19/08/2000	20/08/2000	
19/12/2000	20/12/2000	
05/03/2001	06/03/2001	
15/12/2001		SDS2 TRIP
21/12/2001	21/12/2001	
05/01/2002	05/01/2002	
26/01/2002		SETBACK
19/04/2002	19/04/2002	
11/02/2003		SDS1 TRIP
10/09/2003	13/09/2003	
30/04/2004	01/05/2004	
09/07/2004		TURBINE TRIP
02/10/2004	03/10/2004	
31/03/2005	N/A[3]	N/A
15/04/2005	16/04/2005	
12/08/2005		SDS2 TRIP
07/05/2006	08/05/2006	
20 Shutdown Transients	**13 Shutdown & 13 Cooldown Transients**	**6 Upset Events[4]**

[1] Station outages tracked manually by PLGS technical staff.

[2] Identified in PLGS Reliability Database

[3] Shutdown not present in original PLGS database, but confirmed through visualization of data using ThermAND.

[4] Upset events are counted by ThermAND as Shutdown Transients. The ability to classify these uniquely using ThermAND is under development.

4 SUMMARY

This paper documents the preliminary results of the ThermAND development for fatigue monitoring for PLGS. Descriptions of some typical design basis transients are given as well as with the logic of transient counting in ThermAND. Based on the comparison between transients detected by ThermAND automatically and those transients identified based on the plant data, this study demonstrates that the fatigue monitoring module in ThermAND has the capability to identify and quantify normal transients (shutdown, cooldown, warmup and startup) and provides useful information to track the upset transients. The configuration of ThermAND will be enhanced to include the ability to identify and count all design-based transients. In this way, the fatigue-monitoring module in ThermAND will fulfil the requirement to automatically count and classify station transients, and become a tool for research and industry specialists to manage fatigue throughout plant life and plant life extension.

5 ACKNOWLEDGEMENTS

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