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Usage of DCS Data for Quantifying HRSG Component Life Consumption

by

Jimmy McCallum
Dean Sheffield
Southern Company Generation

Suichi Sun
Systems Design Engineer
Vogt Power International Inc.

Akber Pasha
Technical Director Thermo
Vogt Power International Inc.

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A Babcock Power Inc. Company

Vogt Power International Inc.
4000 Dupont Circle
Louisville, Kentucky 40207
www.vogtpower.com

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ABSTRACT

Combined cycle plants those days are used more and more as peaking units with heavy emphasis on cycling operations. The cycling operation, by its very nature, damages the HRSG components. However this damage does not impact all the components or parts of the components uniformly. Different operating conditions produce different types and intensities of damage. Many times the same operating conditions may cause different damage based on the condition of the unit before the operation begins.

All plants are operated by procedures which are developed based on the unit's constraints. For a Combined Cycle Plant the main components consist of a gas turbine, an HRSG and a steam turbine with a condenser. Each has different constraints which are based on some sort of static life cycle analysis. Based on these constraints, plant operating procedures are developed for each of the operating scenarios (start-up, operations, and shut down). However the components may not experience the pressure and temperature changes in the precise manner as indicated by the static life cycle analysis. For this reason, a dynamic component life consumption program is necessary. These kinds of programs, when developed properly, will estimate the life consumption of HRSG components as the operations progress. One major shortcoming of these programs, however, is the preparation and input of the data to the program. Manual input of data is not only tedious but would also give erroneous results because the calculations needed to determine the proper data ranges and establish the cycle boundaries may not be possible manually. Thus there is a need to have an automatic input of data for the program to be of practical value.

This paper describes the programming requirements and the major hurdles encountered in developing the software to extract the data from a Distributed Control System (DCS) through an Operational Information System (OIS), validate it and then prepare the input for the Life Consumption Assessment and Monitoring Program. The authors will also detail the idiosyncrasies of the plant data as it goes through various stages of handling — from signal generation to recording of the data in the DCS and then extraction by an OIS. The problems encountered and solutions developed will be supplemented by examples from the actual plant data.

INTRODUCTION

All HRSGs are designed to produce a given amount of steam at given pressures and temperatures. The mechanical design is set by the rules as given in the applicable codes and the designers standards. Most of the time the project developer assumes certain plant operating conditions based on the project lifetime requirements. These operating conditions form the basis of the HSRG Design, both thermally and mechanically.

These days, however, the economic necessities, like fuel cost and energy prices, are changing the operating conditions continuously. These changing operating conditions can cause the boiler operating profile to be different than those assumed in the design stage. Consequently the boiler, or more precisely some components of the boiler, may deteriorate faster than others and may require repair or replacement much sooner than may have been anticipated during the original design. The shortening of the expected life under the new conditions would not be bad if it can be static and can be fixed in time at a certain stage. However, the life expectancy estimates change as the operations progress and operating requirements change as a response to changes in today's market place.

It became apparent that a software tool which can assess the impact of changing operating conditions on the life of the critical components would be desirable. Such a tool can continuously update the life consumed and make the operators or the plant mangers aware of the conditions of the critical components. Based on this data, the owners can schedule planned and focused inspections and any other repairs and replacement before such failures might impose a forced shutdown.

Such software calculates the component consumption as the operations progress by continuously updating the total consumption and forecasting the remaining life. To do this, it needs to 'read' the real operating data and use it for calculating the component life consumption. Thus there is a need for filtering routines in the software, which can read the data, clean the data by removing anomalies and data recording idiosyncrasies, substitute missed data, if any, and supply it in proper format for calculations by the life consumption software.

The following paragraphs describes the requirement of such a program and the difficulties encountered in preparing the data for life consumption calculations based on continuous monitoring of the operating data. The steps are clarified using examples from an operating unit's data which shows the typical problems common with these kinds of data.

Combined Cycle HRSG Operating Procedures

The combined cycle Heat Recovery Steam Generator (HRSG) operating procedures generally have three phases: the start-up, operation under load, and shutdown. If the HRSG is fired using duct burners, then another operating phase — ramping to the fired capacity — is also added. The procedures to be followed in any of the phases mainly consist of the valve line-up and load ramps. In simpler terms, the procedure specifies which valves to open, which valves to close, and when and how fast. If some valves are to be operated automatically, when to move these valves from manual to automatic operation is also part of the procedure.

Generally, the operating cycles are classified into three main categories: cold, warm and hot start-ups. Though these terms are extensively used to denote some specific condition of the HRSG or plant, in reality, these terms are too vague and too ambiguous to be of any real distinction unless the conditions are quantified in terms of equipment pressure and temperature.

For a better definition of the operating procedure, the start-up, operation and the shutdown should be identified since these forms a cycle. The HRSG operating procedures can be very simple wherein the HRSG manufacturer specifies a maximum ramp rate, usually pressure increase in the HP drum. The plant designer develops the plant operating procedure using the constraints of all the components (Gas Turbine, Steam Turbine, HRSG etc.). The operator is provided means to control the operations in such a manner that the given constraints are not exceeded. It should be noted that these procedures are based on very general historical practices and do not indicate any consequences of exceeding any of the given constraints.

These days, the specifications are indicating the number of operating cycles and operating hours as shown in the tables below, for the life of the boiler, which is usually 30 years. The HRSG designer uses this data to carry out a Life Cycle Analysis (LCA) of the HRSG critical components. The operating constraints are tightened or the design is changed if any of the critical components can not last the specified number of life cycles. The HRSG constraints thus generated are used by the plant designer to develop the plant operating procedures.

Cycle Requirements

Required Equipment Life = 30 years

	Initial pressure psia	Number of cycles per year	Lifetime cycles
Cold — Cold	0	5	150
Cold	200	30	900
Warm	400	100	3000
Hot	800	200	6000
Load Change	1200	10	300
Trips	2200	10	300

Operating Hours Requirements

Required Equipment Life = 30 years

	Operating pressure	Number of hours per year	Lifetime hours
2x2 fired	2250	2400	72000
2x2 unfired	1835	3600	108000
1x1 unfired	1050	200	6000
1x1 unfired	900	200	6000

Why a Dynamic Life Consumption Estimate is Necessary

A typical Conventional Life Cycle Analysis (LCA) consists of:

* Determining the damage incurred or the "Fatigue Damage Factor" given the intensity of pressure / temperature changes due to the specified start-ups and shutdowns as well as the number of cycles.

* Determining the "Creep Damage Factor" or damage incurred to those critical components experiencing high temperatures for the given number of hours of the high temperature operations.

* Calculation of the "Total Damage Factor" taking into consideration the fatigue-creep interaction.

* This value of total damage factor indicates whether the unit or component will last the given number of cycles under given operating conditions.

Once the Life Cycle Analysis is completed, the customer has the following options:

* If the damage factor is lower than allowable values, then specified starting and operating procedures are confirmed.

* If the damage factor is higher than allowable values, then the customer can:

  - ❑ Change the procedures or the operating cycles and redo the analysis.
  - ❑ Accept the reduced Life Expectancy of the equipment.
  - ❑ Redesign the HRSG component or components and redo the analysis.

Conventional LCA is of very limited use in the field because:

* It can only evaluate a single set of procedures within certain static boundaries.

* The analysis is completed before it is known how the equipment will be operated.

* Its conclusions and usefulness is limited since it rarely simulates the real operations encountered in the field. Procedures based on these constraints can be devised, but in practice they are very difficult to follow. The variables influencing the temperature and pressure gradients are too numerous to control.

* The static life consumption is developed without regard for the severity of the operations, assuming that the operations will proceed in smooth manner.

* LCA is based on assuming an uniform and smooth temperature and pressure ramp rates. However in actual operations these ramp rates are anything but uniform or smooth.

* It does not indicate the consequence or expected damage if the constraints are exceeded.

* Economic optimization in changing cost and price environment is not possible.

Because of these limitations a dynamic Life Consumption estimation tool or software became very necessary to optimize the HRSG operations. This software should broadly be based on the following premises:

* Information for the program to be directly obtained from the operating data as the unit is operated.

* The calculations should be based on a uniform set of codes rather than a mix and match of codes with underlying conflicting or different assumptions.

* The program needs to take into account the specific geometry and connection details of the specific unit components.

* The program should define the basis for various damage stages.

* Always need an Inspection and Monitoring program for the identified critical components to validate the software as well as schedule any corrective action required to preclude the possibility of a forced shutdown.

* Starting-up or shutting-down ‘fast’ should become an ‘option’ based on economic optimization factors rather than ‘prohibited’ because of not satisfying the assumed life consumption term.

Operating Data Based Damage Estimating System Architecture and Data Access

To estimate components’ life consumption based on operating data, it is necessary to establish a dynamic connection between operating conditions and resulting stress imposed on various HRSG components. Finite Element Analysis (FEA) would be used to quantify the impact of operating conditions on life expectancy of critical HRSG components. The data from FEA combined with the results from analysis on transient behavior of the unit can be used to develop correlations between a set of operating conditions and the corresponding thermal stress and mechanical stress at various locations of a component. By analyzing combined stress at those locations, the weakest point for crack initiation can be determined and life consumption under the given conditions can then be estimated.

Since the Dynamic Life Consumption estimation is calculated based on the actual operating data rather than the assumed static data, the data should convey the operating conditions correctly. Otherwise the results will be grossly over or under estimated. This happens because of the critical nature of the input. For example, one of the most critical variables influencing the life consumption is the temperature difference between various components. Data for the program should be directly obtained from the operating data.

* The data should be smooth. If not, the program should be able to ‘smooth’ out or normalize the data, drops out ‘bad’ data.

* The data should be pertinent to the requirements of the program.

* The data should be consistent. The program correlations need to use ‘stable’ data.

A program based on such concepts has been tested and is installed and operating on several of Southern Company combined cycle plants. Southern Company adopted AspenTech as its plant Operating Information System (OIS) in 2002. Aspen Process Explorer has been installed on client machines to access plant operation data and perform post processing and statistical calculations. For machines running Aspen based applications, Aspen Desktop ODBC (Open Database Connectivity — ODBC) is installed on client machines to access the InfoPlus.21 database through the SQLplus server (Structured Query Language — SQL), which is a component of InfoPlus.21 Server.

The program was initially developed for Aspen system client machines. To enhance the flexibility of data accessing, dual OIS data access modes have been implemented with both DSN (Database Source Name — DSN) connection and DSN-less connection through InfoPlus.21 Database APIs (Application Programming Interface — API). For use by plant personnel, the Plant Edition uses local DSN files to access operation data, while the Server edition uses non-DSN connections for quick switching among different plants/units and performing administrator post calculation tasks. For DSN connections, it is necessary to create a data source through windows ODBC Data Source Administrator and perform SQLplus advanced setup. Aspen ODBC connections are customized to satisfy data transfer requirements, including maximum rows for a package and string/character handling.

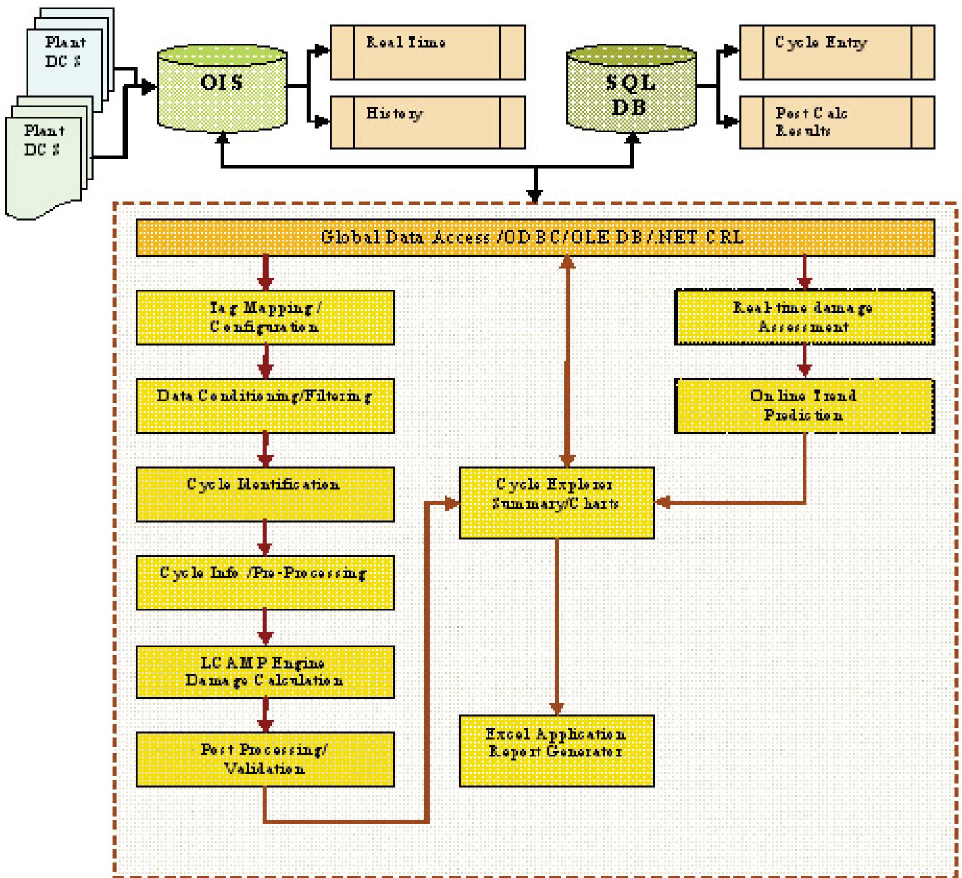


Figure 1: ODB damage estimating system architecture and components

A SQL database is used to store processed cycle information including itemized life consumption data for individual critical HRSG components as well as cycle images. The database resides on a SQL 2000 server and a group of stored procedures are implemented to perform statistical and analyzing calculations. Summary and reports can be generated from the saved data. An Excel application is used to provided tabular and chart information for different reporting purposes.

OIS Tag Mapping and Link to Aspen InfoPlus.21

To use operating data for Life Cycle Analysis, the user needs first to establish a link between LCA parameters and the OIS system. This is done by mapping OIS tag names to LCA parameter names, a process called LCA configuration. Generally, GT power output and outlet flue gas temperature, all major steam side conditions and drum metal temperature need to be passed to the calculation engine. Once configured, all the mapping can be saved to a configuration file for a specific HRSG, and it can be reloaded for future calculation.

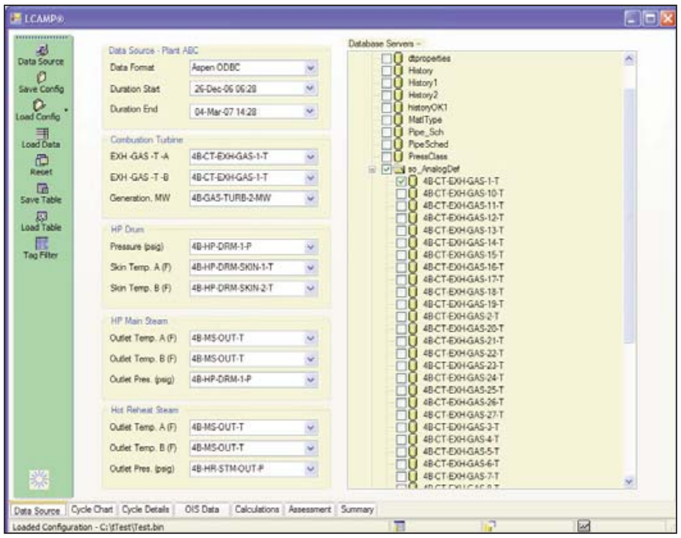


Figure 2: LCAMP tag mapping and data source link

For the damage factor (historical cycle) calculation, the Aspen InfoPlus.21 history table serves as the main data source while real time tables for each individual tag are used for quality control and data validation purpose. The Aspen system provides high flexibility of data collection intervals. The time interval of data transferring from OIS to the program is carefully selected to balance program performance and accuracy of the calculation.

The LCAMP™ program data component automatically detects all the serves which are accessible through the network. Once a target server is selected, a filtered tag list will be presented to user to be selected for tag-mapping. This makes the mapping process relatively easy and the key words for the filter can be customized from an Administrating tool.

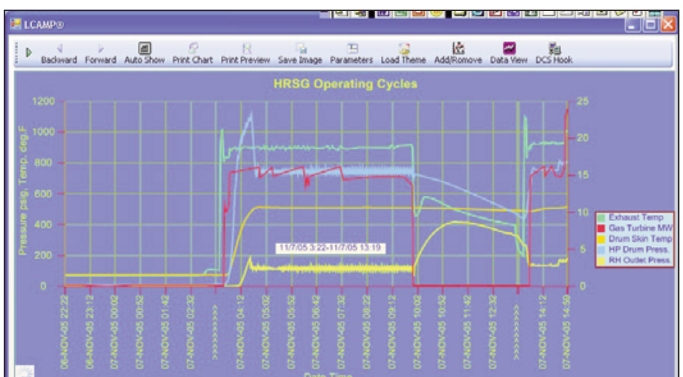
Cycle Identification and Counting

Cycle identification is a major step in a dynamic life consumption assessment process. It is essential not only to identify a cycle as a whole period, but also to identify different stages of the cycle, i.e., start up, operating load period and shut down. During a cycle counting process, the program continuously checks the status of gas side and steam/water side conditions by evaluating ramp rate, slope change and continuity. Parameters evaluated include GT exhaust temperatures, GT output, HP drum pressure and metal temperature, etc. A cycle is identified based on both gas side and steam side conditions with the consideration of operating procedure and the corresponding responses.

Count	Start	End	Duration (hrs)	Max Drum Pres.	Max Drum DT	Max GT MW
12	6/27/2006 4:12:00 AM	6/28/2006 8:04:00 AM	27.9	2019.5	93.7	155
13	6/28/2006 8:12:00 AM	6/29/2006 8:08:00 AM	23.9	1851.9	128	154
14	6/29/2006 8:12:00 AM	6/30/2006 7:02:00 AM	22.8	1857.2	121.1	156
15	6/30/2006 7:10:00 AM	7/1/2006 7:43:00 AM	24.6	2022.2	101	158
16	7/1/2006 7:45:00 AM	7/2/2006 6:45:00 AM	23	2029	131.9	154

Figure 3: An operating cycle with cold start-up

Most of the time, a pre-identified cycle needs to be revisited or cross checked with adjacent cycles to eliminate a false start-up condition or to fine tune the start up time as well as time durations of each stage of the cycle. Since operating manner affects the profile of those parameters, cycle counting criteria should be customized based on plant operating procedures for establishing proper variable sensitivity, limits and floor conditions.



Count	Start	End	Duration (hrs)	Max Drum Pres.	Max GT MW
1	07-NOV-05 03:22	07-NOV-05 13:19	10	1116.3	16
2	07-NOV-05 13:29	08-NOV-05 06:12	16.7	1512	134
3	08-NOV-05 06:22	09-NOV-05 05:03	22.7	1507.3	130
4	09-NOV-05 05:13	15-NOV-05 09:17	148.1	1562.6	135
5	15-NOV-05 09:27	17-NOV-05 01:25	40	1973.7	157
6	17-NOV-05 01:35	17-NOV-05 14:59	13.4	1430.4	121

Figure 4: An operating cycle with warm start-up

Pre-start up conditions have a high impact on the drum damage calculation, which predicts thermal stresses based on metal temperature differences across the drum wall. Generally, a heat balanced drum condition is assumed before a start up. The drum temperature before start up will be used as the basis for temperature difference calculation. Drum pressure at start up is a main parameter to distinguish among cold, warm or hot starts.

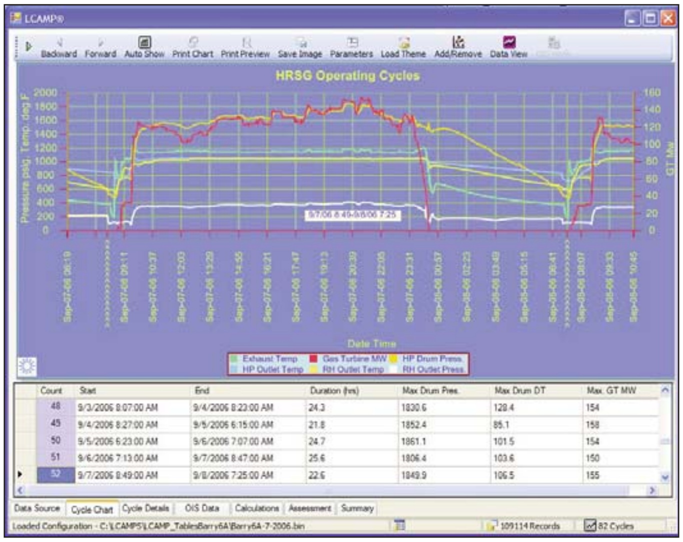


Figure 5: An operating cycle with hot start-up

DCS Data Conditioning and Cycle Info Pre-Processor

The stress intensity and allowable cycle calculation algorithm requires valid temperature and pressure inputs extracted from OIS data. Generally, the metal temperature difference across the drum wall or steam temperature ramp rate at the headers of final HP superheaters or reheaters are the main inputs for these calculations. Ideally, drum metal wall temperature difference would be needed for both steam space and water space. If a measurement is not available, a dynamic simulation algorithm is used to calculate the values based on other system parameters. Depending on the material and style of welding joints and attemperator design from the target HRSG, additional inputs could also be needed for the calculations.

It has been a major task to deal with irregular OIS data during the cycle counting and cycle pre-processing processes. Irregular OIS data will not only cause mismatched cycle counting but also affect the accuracy of damage calculations. So whenever a system detects irregular data, it is corrected or normalized. Irregular OIS data could result from either system/instrumentation related issues or due to abnormal operation conditions. Instrumentation and OIS system related issues include:

* Dropped data	* Discontinuities
* Bad instrumentation	* Interruptions due to system upgrading

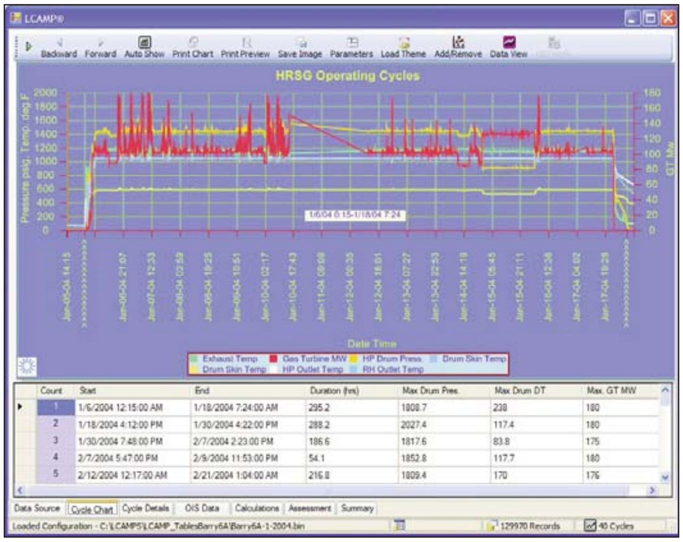


Figure 6: Cycle with interrupted OIS data

Data validation algorithms are implemented for filtering and regulating the OIS data. For each main LCA parameter, the program tracks the slope changes, ramp rates and moving profiles over the cycle period. Dynamic link lists are maintained for each parameter to store that information. A moving trend can be established for the parameter for the current stage of the cycle. Irregular data can likely be identified from the comparison of trend to the retrieved values, with the help of cross checking of steam and GT side operating conditions as well as OIS system flags for data validation. System or instrument related irregular OIS data can either be dropped or replaced with predicted values based on the type of data failure.

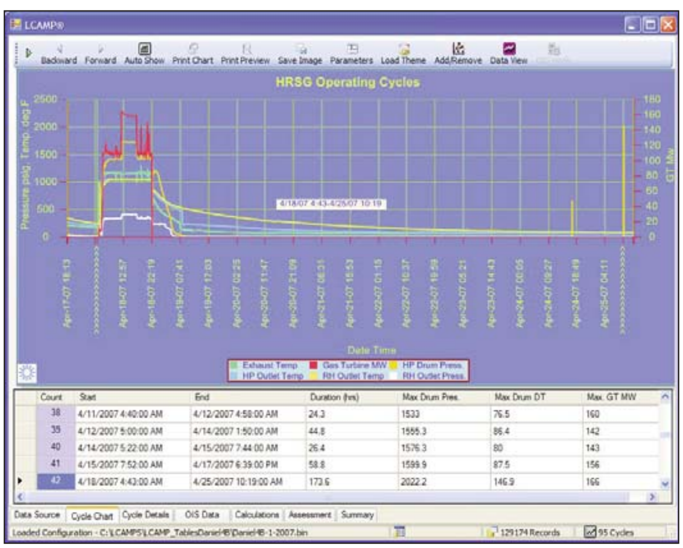


Figure 7: OIS data with false drum pressure “spike” output

In addition to fetching bulk data packages from OIS, the program can also access the OIS system dynamically by querying individual tags for a given time period or call stored procedures through the SQLPlus. This capability is useful when there is a need to validate retrieved OIS data with additional operating information. For parameters with multiple measuring devices, such as exhaust temperature or drum pressure, data can be validated with a comparison and exclusion method based on the reference tag names. The Aspen system also presents a status flag for each tag value. A status flag indicates any generic failure or abnormal condition for an associated tag value.

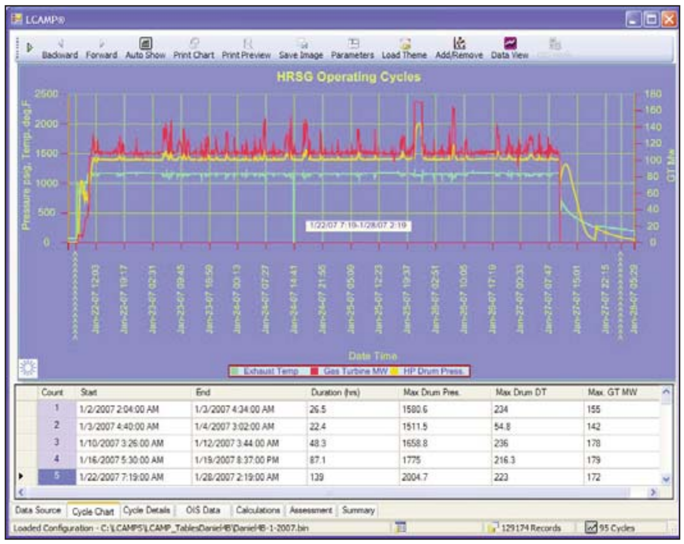


Figure 8: OIS data with flue gas temperature discontinuity

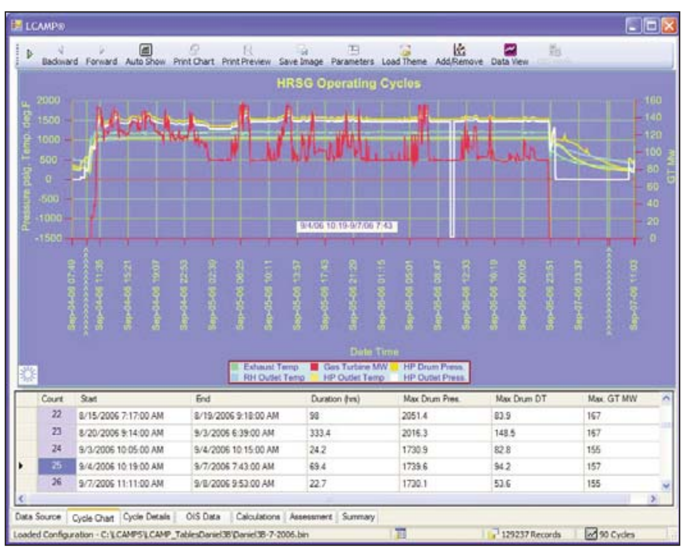


Figure 9: Drum pressure data failure caused by bad instrument or system connection

Irregular data is not just associated with system or instrument related issues. Irregularities in data can also be caused by abnormal operating conditions related to operating procedures or design conditions such as:

* Trips
* Rapid ramps
* Fired operations
* False Starts

To make the stress calculation correct, data collected under the above conditions need to be normalized or regulated to satisfy the assumptions on which stress correlations are developed. If drum pressure is used to predict internal metal wall temperature through saturation temperature, the pressure needs to be corrected by a transient response compensation factor when rapid pressure ramp occurs. This transient response compensation factor takes into account the dynamic response of drum water temperature to pressure change and is a function of pressure ramp and drum transient behavior.

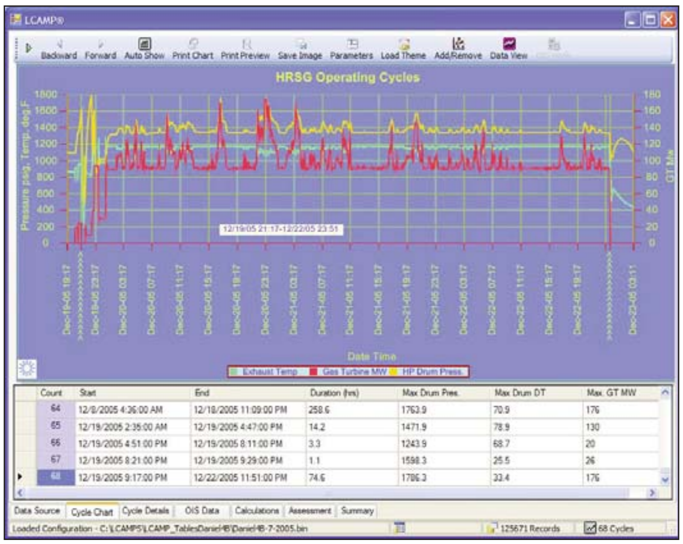


Figure 10: Pressure values that need transient response compensation

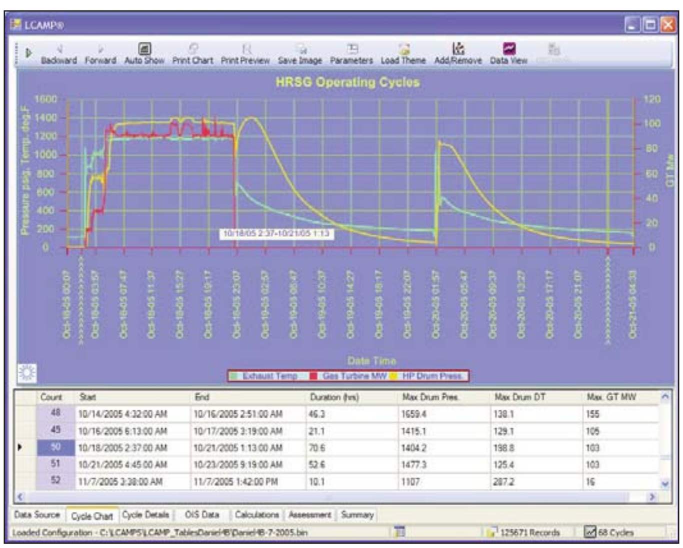


Figure 11: OIS data with failed start-up

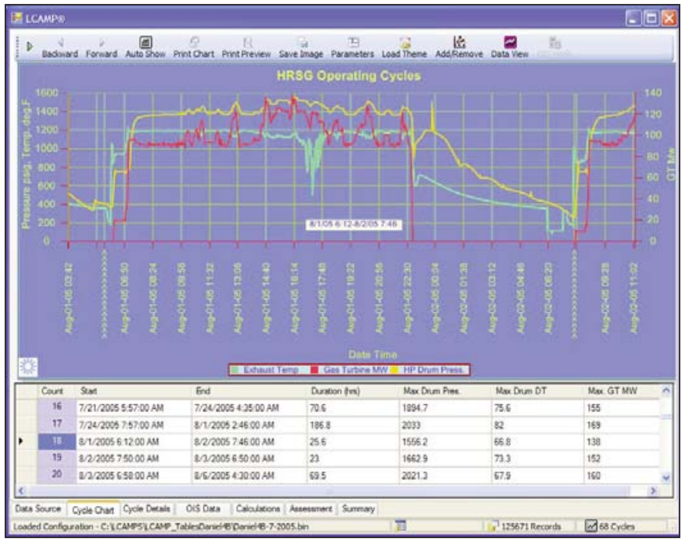


Figure 12: OIS data with rapid ramps

Life Consumption Estimating and Post Cycle Analysis

Post calculation analysis summarizes the total number of cycles with different types of start-up and associated accumulated spent life for each category.

To identify unit start up time, it is necessary to monitor the gas turbine operating mode and steam turbine bypass valve position.

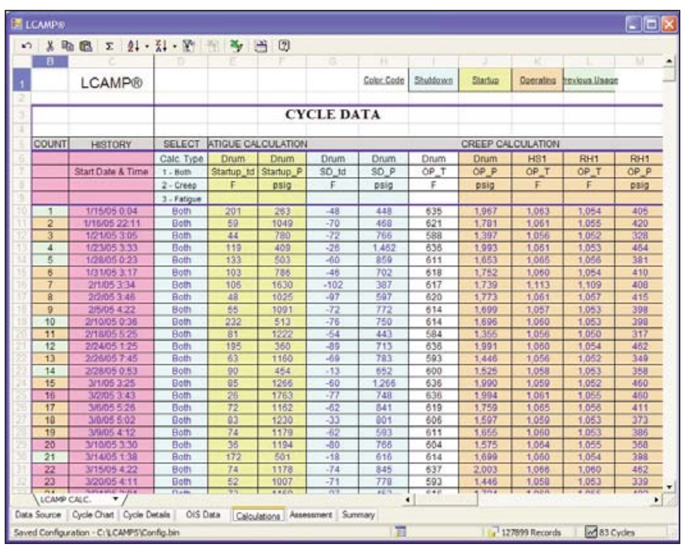


Figure 13: Allowable cycles /allowable hours calculation from processed OIS data

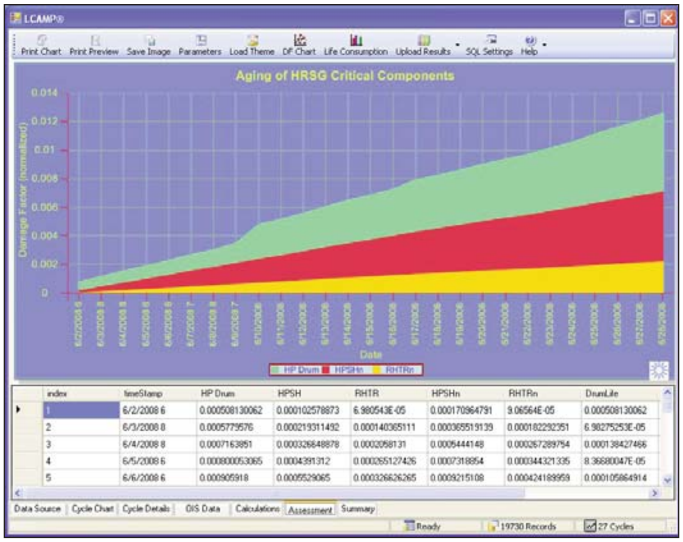


Figure 14: Accumulated components life consumption in a given time period

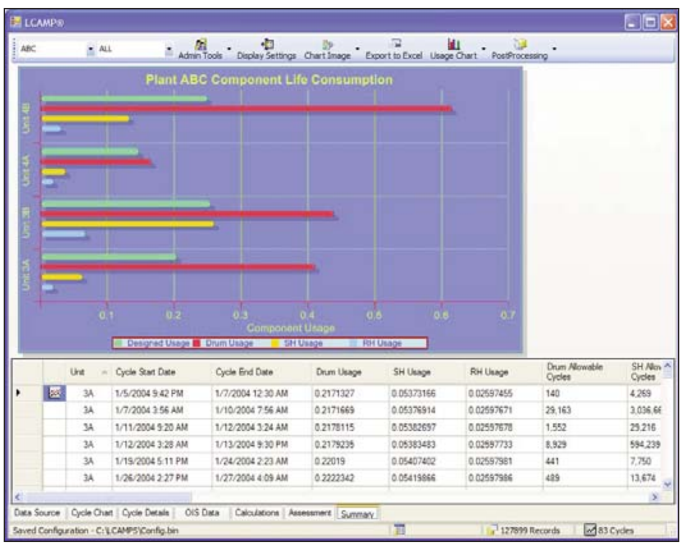


Figure 15: Itemized life consumption for each unit of a plant

CONCLUSION

These days, combined cycle plants operating under cycling mode have become very popular. As a result, there is an increasing need for a reliable and effective way to evaluate the impact of cycling operations on the life expenditure of HRSG components. Compared to the traditional design stage life cycle analysis or stress monitor type life assessment process, Operating Data Based life cycle analysis is a dynamic and continuous life consumption assessment process which requires no additional instrumentation. This technique uses pre-processed operating data to calculate stresses and estimate life consumption for critical components.

Features and benefits for an operating data based life analysis include:

* Capability to back process historical operating data and establish a life consumption history for critical components of a HRSG. This makes it feasible to evaluate life consumption for an existing HRSG unit.

* Flexibility to accommodate operating procedures or operating pattern changes over the course of a unit's operating life. By tracking and evaluating every cycle, impacts from those changes can be analyzed more accurately with the consideration of any specific conditions involved and the usage of embedded compensation or adjustment algorithms.

* Filter and pre-processor can be developed for a target OIS system. Effects from system interruption, instrumentation failures and abnormal parameter fluctuations can be eliminated or regulated to achieve accurate estimating.

* Integrated with an adequate OIS system it is flexible in analyzing various units in the fleet and determining the difference. Provides an effective tool to aid operational improvements and economic optimization.

The results of any program, however, are only as good as the data it uses. Processing and preparing the data for use by such a dynamic program is very crucial in establishing the validity of the results. The paragraphs above describes some of the most common irregularities that can occur in any operating data generating and reporting system, and the means used to normalize the data without affecting the accuracy of the results.

If certain data is completely out of range, the program still gives the results but these results are flagged so that the analyzer can look into the data in detail and make corrections, if needed, using some supplementary measurements.