APPLICATION OF CHAOTIC TIME SERIES FOR THE CHARACTERIZATION AND CONTROL OF FLUIDIZATION AND COMBUSTION SYSTEMS

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Abstract

Oak Ridge National Laboratory and Babcock and Wilcox, a prominent U.S. boiler manufacturer, have collaborated under this CRADA to investigate the application of deterministic chaos theory to improve the performance of fossil fuel boilers. The types of boilers investigated were coal-fired fluidized beds and more conventional pulverized coal systems. The results of this investigation demonstrate that chaotic time series analysis of boiler signals (e.g., pressure, acoustic and/or optical signals) can be used to characterize the combustion dynamics with greater accuracy than is possible with conventional signal analysis. Further, it is expected that these new analysis techniques will lead to a new generation of boiler diagnostics and control technology that can make U.S. industry more competitive in the world boiler market. Babcock and Wilcox is initiating follow-on internal and external research to further develop the technology.

CRADA Objectives

This CRADA was initiated to promote collaboration between Oak Ridge National Laboratory (ORNL) and Babcock and Wilcox (B&W) in applying chaotic time series analysis (CTSA) to characterize boiler measurement signals. CTSA is a new technique developed from deterministic chaos theory that is able to extract previously unavailable information from measurements of nonlinear dynamic processes. The specific objectives were to identify boiler systems and measurements for which CTSA might provide improved information extraction, to collect experimental data from those systems, to process the experimental data with newly developed CTSA algorithms, and to demonstrate that the new information is useful for improving boiler performance.

Success in Meeting Objectives

All the objectives above have been met, both for fluidized bed combustors and pulverized-coal-fired boilers. Test measurements were collected from the 9-inch-by-9-inch test fluidized bed at the B&W Alliance Research Center (ARC), the Tidd demonstration pressurized fluidized bed (PFB) facility at Brilliant, Ohio, a cold scaled model of the Tidd PFB at Massachusetts Institute of Technology, the 5 MBtu/hr Small Boiler Simulator (SBS) pulverized coal combustion test unit, and the 100 MBtu/hr Clean Environment Development Facility at the ARC. From these measurements the CRADA team demonstrated the extraction of previously unavailable dynamic information characterizing the performance of all the above units. The new information obtained for the fluidized beds is particularly relevant to concerns regarding scale-up between small pilot combustors and large full-scale systems. The new information from the pulverized coal combustor indicates that it may be possible to combine CTSA with optical flame scanners to achieve
unprecedented monitoring and control of flame stability and emissions.

Benefits to DOE

Demonstration and transfer of advanced technology to U.S. industry are central elements of the DOE Fossil Energy Program mission. The successful completion of this CRADA demonstrates the commercial relevance of the CTSA research sponsored by the DOE Fossil Energy Program through Morgantown Energy Technology Center (METC). Commercial application of this technology is expected to provide U.S. industry with additional options for burning fossil fuels such as oil and coal with greater energy efficiency and reduced emissions of pollutants and greenhouse gases. Also, the transfer of this technology to a prominent U.S. boiler manufacturer is expected to improve their competitiveness with foreign boiler manufacturers. Beyond supporting the DOE mission, this CRADA has improved the knowledge of DOE researchers regarding the concerns of the U.S. boiler industry, and it has allowed the researchers to improve their technical capabilities in boiler analysis.

Technical Summary of Work Completed

Nonproprietary technical details of the CRADA results have been published in the following open-literature papers (attached):


Inventions/Concept Disclosures

The following new ideas were jointly developed by ORNL and B&W during the period of performance of this CRADA.

1.) Flow Quality Analyzer for Two-Phase Pipeline Flow by T. A. Fuller - B&W internal tracking No. RNI-4546-A.
2.) Acoustic Feedback for Burner Control
3.) Passive Acoustic Monitoring of Gas-Solids Flow in a Vessel
4.) Perturbation Diagnostics of Fluidized Beds
5.) Active Acoustic Probe for Gas-Solids Flows
6.) Flame Diagnostic Tool Based on the Correlation Integral

The latter five ideas are currently being assigned B&W internal tracking numbers. All six are documented with ORNL and B&W CRADA contract managers.

The following patent application was formally submitted by B&W during the period of performance of this CRADA. This patent application was conceived before implementation of the CRADA, but subsequent work done under the CRADA has refined B&W’s concept of how the patent idea can be implemented.


Assessment of Commercialization Possibilities

B&W envisions commercial application of the CTSA techniques in three general areas. First, CTSA can be used as a diagnostic tool in the laboratory and in the field. As a research and development diagnostic tool, CTSA will continue to enhance boiler vendors’ understanding of key nonlinear processes such as fluidization and combustion. In the field, CTSA diagnostic tools can be used by service engineers to balance burners more closely or troubleshoot problems such as poor fluidization and burner instabilities. Second, CTSA can be integrated into advanced plant monitoring and control systems. The superior sensitivity of CTSA techniques to small changes in operating conditions can be used to provide operators advanced warning of developing problems. The sensitivity of CTSA techniques can also be used to enhance the performance of traditional feedback control strategies. Most promising, however, is the use of CTSA in advanced, active control systems. In theory, CTSA-based active control strategies can produce and maintain operational conditions previously unattainable with traditional control strategies. Finally, CTSA can be used to guide the design of new boilers and boiler components. For example, scale-up correlations using CTSA techniques can be developed and used to help design boilers based on laboratory data.

The probability of commercializing CTSA in one or more of the above mentioned areas is high. B&W has found CTSA to be a valuable engineering tool and is continuing to develop applications and products using CTSA. This CRADA has greatly reduced the time to commercialization for any CTSA-based B&W product.
Plans for Future Collaboration

Additional collaborations between ORNL and B&W are now underway under the sponsorship of the Electric Power Research Institute and the DOE Fossil Energy Program. These collaborations are primarily focused on the further development of CTSA algorithms for diagnostics of pulverized coal boiler performance.

Conclusions

ORNL and B&W investigators agree that the usefulness of CTSA for characterizing boiler measurement signals has been successfully demonstrated. Further, it is expected that CTSA algorithms will be more effective in providing information important for flame diagnostics and control than conventional algorithms. These new algorithms have a significant potential for leading to a new generation of boiler diagnostics and control technology that can make U.S. industry more competitive in the world boiler market.
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