GRI INDUSTRY WORKSHOP ON ADVANCED COMBUSTION AND PROCESS CONTROLS

FINAL REPORT
(June 1989 – February 1990)

Gas Research Institute
8600 West Bryn Mawr Avenue
Chicago, Illinois 60631

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ON ADVANCED COMBUSTION AND PROCESS CONTROLS

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Prepared by

John M. Fildes

IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616-3799

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GRI Project Manager
Michael A. Lukasiewicz
Manager, Technology and Components Research

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GRI DISCLAIMER

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This report summarizes the findings of a workshop sponsored by GRI to identify research and development priorities in the areas of combustion control and materials processing. The workshop was conducted by IITRI, and provided a forum for the exchange of ideas by experts from all segments of the industry. Their opinions on a number of relevant matters were obtained from a questionnaire distributed to all participants and from group discussions.

The report describes emerging process control techniques and sensor technology. It also provides a comprehensive summary of the workshop discussions and recommendations, summarize the objectives of pertinent GRI project areas and the plans of other funding agencies, and describes several important research opportunities.

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19. ABSTRACT (continued)

In formulating its recommendations, IITRI paid careful attention to GRI's objectives for the Industrial Controls Project Area:

1) Development of process equipment and control strategies to improve product quality
2) Investigation of automation technologies and expert systems that will increase the productivity, efficiency, and flexibility of gas-fired processes
3) Formulation of design standards for fail-safe furnace operation and integration of process control components
4) Development of automated combustion controls that are low in cost, efficient, and environmentally sound.

RESEARCH SUMMARY

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Objective: To define R&D priorities for advanced control of combustion and materials processing related to natural gas use in industry.

Perspective: New possibilities for advanced process control have been created by availability of powerful computers and the advent of new software techniques such as artificial intelligence. Emerging control options include fault diagnosis and fault tolerant control, microsensors, sensor fusion, state estimation, supervisory control, and process simulation. These advances answer industry's need for better productivity, improved product quality, better efficiency, and reduced environmental emissions. Advanced control technologies can provide industrial users of natural gas with control options to address these needs.

Results: A GRI-sponsored workshop provided a forum to solicit industry's priorities for development and application of advanced control technologies. High priority opportunities in control theory are full implementation of model-based control, statistical process control, and development of forecasting methods. Artificial intelligence provides powerful tools to meet these opportunities, but successful application of AI will require better sensors for process parameters such as temperature and new sensors for on-line evaluation of product quality features such as microstructure. For combustion control, specific priorities include development of more reliable flame detection systems, better exhaust gas sensors, and lower-cost controls for multiple burners. Priorities for materials processing are development of in situ non-contact temperature sensors, monitors of the composition of gas fuel streams, and on-line non-destructive evaluation sensors of product quality characteristics. Also, R&D should explore practical methods for applying on-line models to estimate the state of a process from limited sensor data.

In light of the wide variety of process heating operations, the workshop participants made several recommendations for GRI's R&D program: (1) GRI should cooperate with industrial concerns and other funding agencies to define R&D needs that span the various market segments, and (2) GRI's programs should stress development of broadly applicable generic technology and transfer technology developed in other areas such as the automotive sector.

Approach: IITRI conducted a workshop to identify R&D priorities for control of combustion and materials processing. The workshop provided a forum for discussion of advanced controls technology by a diverse group of industrial and academic experts. The participants had backgrounds in combustion control, materials processing, and sensor and control technologies. At the meeting, formal presentations covered operating practices and needs, economic incentives, and the nature of emerging technology. To prioritize industry's needs, the participants were divided into two discussion groups, one addressing combustion control, the other materials process control. IITRI also surveyed the plans of other funding agencies in order to ascertain coordinated funding opportunities and areas of R&D overlap. The information gathered from these sources was assembled into this report.

Project Implications: R&D in the Industrial Processes subprogram at GRI focuses on technologies having diverse applications in many industries and on industries where gas-fired technologies offer significant productivity, environmental, and energy benefits. As part of the effort to develop advanced gas-fired systems, GRI sustains technology base efforts in combustion, advanced materials, and controls. The choice of projects and direction of R&D activities in the industrial controls project area and the industrial process program in general is guided by interactions with representatives from the gas industry, the manufacturing community, and end users. The controls workshop is one vehicle to bring the GRI constituents together and reach a consensus on R&D priorities. The sensor R&D opportunity identified by the participants of the workshop will be the subject of a request for proposals to be issued by GRI in 1990.

GRI Project Manager: Michael A. Lukasiewicz
Manager, Technology and Components Research

EXECUTIVE SUMMARY

Program Background

GRI established a program at IIT Research Institute (IITRI) to solicit industry input and identify R&D priorities in the area of sensors and controls for industrial process heating. Industrial sensors and controls are the focus of a new GRI project area that addresses the productivity, control of product quality, and reduced emissions needs of the process industries. The goal of the GRI Industrial Control Project Area is to provide users of natural gas with advanced sensor and control technology.

Traditional process control, also called regulatory control, involves maintaining process parameters at set point values. The values of set points are established by trial and error, and less frequently by statistical methods. This control strategy assumes that the process can be designed to be sufficiently insensitive to uncontrollable interferences such as normal variation in feed stocks. Increased market competition and tighter environmental regulations necessitate better set point selection and tighter process control. Availability of powerful computers and new software techniques has stimulated the development of advanced control strategies, namely supervisory and intelligent control.

In supervisory control, additional computation functions augment conventional regulatory control. This involves interconnecting local (i.e., regulatory) controllers with a supervisory computer. The distributed nature of functionality in this approach provides fault tolerance and places fewer demands on the communications bus. Supervisory control provides several advantages. It allows estimation of the state of the process from a limited amount of sensor data. It also facilitates fault diagnosis and process simulation.

Eventually, a further advance in control could be provided by coupling on-line non-destructive evaluation sensors with detailed process models. This approach, called intelligent control, would provide direct control of quality during materials processing. In this case, the process model would have to relate quality characteristics to controllable process factors.

Full application of advanced control strategies will require development of generic control algorithms, improved combustion sensors and control systems, new process sensors and modelling techniques, and integration of combustion and process control systems. This interdisciplinary nature of advanced controls technology has been a significant barrier to advancement in this field.

To evaluate recent advances and industrial needs, IITRI conducted a workshop for GRI. The results of the workshop were augmented with a detailed questionnaire that was provided to the participants. IITRI also evaluated the plans of other funding agencies, and integrated this information with GRI's objectives to identify R&D priorities for industrial process control. These recommendations and the background information were compiled into a report for GRI.

Technical Approach and Achievements

The GRI Industrial Controls Workshop, held in Chicago on August 23 and 24, 1989, provided a forum for a diverse group of experts to discuss control of combustion and materials processing. The 55 participants represented GRI, suppliers of natural gas, industrial users, and vendors of industrial controls. The background of the participants covered a variety of technical specialties, including production and control engineering, material science, knowledge engineering, and techno-economic analysis. The workshop demonstrated GRI's commitment to R&D programs that enhance the value and efficiency of gas heat generation and utilization.

The first day of the workshop was devoted to presentations describing current practices, economic incentives, operating needs, and the nature of emerging technology. On the second day the participants took part in two working groups. One group addressed combustion control, while the other considered control of materials processing. Each group discussed the match between operating needs and emerging technology. They also defined R&D priorities.

All the objectives of the workshop were achieved. The conference established a comprehensive, pragmatic view of combustion and industrial controls and highlighted the importance of natural gas within process industries. The participants gained an overview of the controls industry and reached consensus on all important issues. The integration of strategic issues, economic incentives, and technological opportunities helped establish realistic R&D priorities that will meet the needs of the marketplace. Finally, industrial users of natural gas will benefit from improved coordination of R&D activities in the component technologies that form the basis of advanced controls.

Other Agency Funding

To determine the funding plans of other agencies, IITRI consulted DOE, NSF, the Air Force, NASA, and EPRI. All these agencies are funding work that could impact industrial controls technology. DOE sponsors controls R&D through its ECUT ($2.4 million in FY89) and OIP ($2.4 million in FY89) programs. R&D efforts include sensor and controls development, laser diagnostics and measurement techniques for combustion, multidimensional computer models for combustion control, and innovative material processing using artificial intelligence techniques. NSF supports research on systems approaches to controlling chemical and thermal processes. Emphasis is placed on fault diagnosis and application of artificial intelligence. EPRI spent $6.9 million (FY89) to support R&D on improved technologies for productive use of energy in industry; part of this funding was for sensors and controls. EPRI funds R&D Application Centers including the Center for Materials Fabrication (Columbus, Ohio) and the Center for Metals Production (Pittsburgh, Pennsylvania). Part of EPRI's FY89 $9 million exploratory research program budget supported work on application of expert systems for boiler start-up and heat-rate analysis. NASA-Langley spent about $5 million in FY89 on non-destructive evaluation (NDE) research for microstructure characterization and flaw detection. Although NASA's programs are not specific for materials processing, much of the NDE research might be suitable for application to on-line NDE for use in process control. NASA-Langley also opened a new $2 million NDE research facility in 1989. The Air Force is funding work to apply laser induced fluorescence to surface thermometry. This work might be adapted for use during processing of materials.

R&D Priorities

The workshop participants felt that advanced supervisory process control would impact industry within five years. The result will be widespread use of artificial intelligence, sensor fusion, and state estimation. Use of mechanistic models and on-line non-destructive evaluation was felt to be at least 10 years in the future.

R&D priorities were cited in three areas: control theory, combustion control theory and sensors, and control strategies and sensors for materials processing. For control theories, high priority research opportunities include full implementation of model-based and statistical process control, and development of forecasting tools. Artificial intelligence techniques were recognized as powerful control tools to improve the safety and performance of industrial processes, but their use will require many advances in sensor technology.

For materials processing, the workshop participants indicated specific needs for sensors of temperature, product characteristics, and natural gas composition. In the area of temperature sensing, measurement at the wall of a furnace was deemed insufficient to ensure adequate productivity and consistent quality. Knowledge of the core temperature of each part is required for adequate control. This could be achieved by a heat transfer model, coupled with measurement of the surface temperature of each part. Direct measurement of the components' internal temperature would be even better because this approach would not require development of a complex thermal transfer model.

With respect to natural gas fuel, the participants were concerned that composition changes will hinder atmosphere control in furnaces. They felt that R&D is needed to find a reliable monitor for the composition of gas fuel. In the area of non-destructive evaluation (NDE), they stressed the need for sensors to assess product quality during manufacture. NDE sensors would be combined with artificial intelligence technology to provide real-time process modeling and simulation. There is also a need for generic modeling tools and methods for integration of sensors and process models.

For combustion control, the participants cited needs in the areas of flame detection and exhaust gas monitoring. More reliable flame detection systems are needed because existing systems produce an unacceptable number of false alarms. The participants thought it was important to distinguish between burner failure and problems with the detection system. For exhaust gas monitoring, they felt that single-point oxygen concentration measurements were inadequate to control multiple burner systems. R&D is needed to develop sensors for cost-effective multiple-point measurements of oxygen levels. Also, inexpensive NO_x sensors are needed for advanced burners being developed by GRI.

To ensure that R&D efforts match industry's needs, the workshop participants suggested that GRI serve as a coordinator of R&D activities. Additionally, GRI's R&D programs should stress development of broadly applicable generic sensor technology and transfer of technology developed in other areas such as the automotive sector. For supervisory control, the participants felt that R&D should explore practical methods for applying on-line models to estimate the state of a process.

Recommendations

R&D programs in the following areas are recommended to address the priorities identified by the workshop participants.

For control theory and systems:

- Application of sensor fusion and AI technology for improved fault diagnosis and safety assessment
- Evaluation of state estimation techniques and development of state estimators for unmeasurable critical process variables
- Research and development for intelligent control by distributed model-based process control.

For control of combustion and materials processing:

- Development of monitors for the composition of natural gas fuel
- Development of low-cost exhaust gas sensing technology for oxygen, carbon monoxide, and nitrogen oxides
- Development of *in situ* non-contact temperature sensors for industrial furnaces
- Development of lower-cost controls for multiple burners and more reliable flame detection systems.

CONTENTS

CONTENTS (continued)

TABLES

1. INTRODUCTION

This report is the culmination of a GRI sponsored workshop to identify R&D priorities in control of combustion and materials processing. IITRI conducted the workshop, providing a forum for discussion of these subjects with a diverse group of industry experts. Opinions on a wide spectrum of related topics were obtained from questionnaires distributed to workshop participants. As part of its report, IITRI compiled information on the funding plans of other private and public funding agencies. To formulate its recommendations, IITRI has been guided by GRI's objectives for the Industrial Controls Project Area, which include:

(1) Development of process equipment and control strategies to improve product quality

(2) Investigation of automation technologies and expert systems that will increase the productivity, efficiency, and flexibility of gas-fired processes

(3) Formulation of design standards for fail-safe furnace operation and integration of process control components.

(4) Development of automated combustion controls that are low in cost, efficient, and environmentally sound.

In addition to delineating R&D priorities, this report provides important background information on emerging process control techniques and sensor technology, much of it provided by formal presentations at the workshop. The report also provides a comprehensive summary of the proceedings of the workshop discussion groups and summarizes the objectives of pertinent GRI project areas and the plans of other funding agencies. The report also contains descriptions of important research opportunities.

1.1 CONTROL SYSTEMS

Control systems run the gamut from dedicated hardware to large distributed control systems that network many smaller subsystems. Dedicated hardware usually has a very specific control function. Larger systems tend to partition the functionality to achieve particular performance characteristics,