Developing an Advanced Control Strategy to Optimize Heat-Treating Processes

Jake Fotopoulos – Air Products and Chemicals, Inc., Allentown, Pa.

Optimization of a facility using automation and advanced controls can improve productivity and reduce costs. A five-step process to accomplish this is discussed. Help exists for companies desiring an analysis of their entire process.

With rising costs of energy, slimmer profit margins and tighter specifications on product quality, the metals-processing industry continues to look for ways to increase productivity and reduce costs. The "Roadmap for Process Heating Technology", published in 2001, identified the following critical requirements for the industry[1]:

- Advanced sensors
- Predictive models
- Increase productivity
- Decrease total costs
- Decrease product costs
- Improve energy efficiency

Most of these needs were originally identified over 20 years ago. Surprisingly, they have still largely gone unfulfilled due to:

- Few direct process-measurement sensors
- Few low cost, accurate, rugged, non-intrusive sensors
- Excessive failures and inaccuracies of thermocouples
- Inability to reliably control processes
- Lack of smart controls
- Lack of cost-effective control devices

To be competitive in today's market, metals-processing manufacturers need to increase their awareness of the potential solutions that are now available. Advanced sensor, control and optimization technology has been used successfully to improve productivity and reduce costs in other areas, such as the refining and chemical industries, and can provide similar benefits in the metals-processing industry. This concept has been identified in the "Heat Treating Technology Roadmap" (Vision 2020), which places a significant emphasis on process controls as a vehicle to achieve the overall objectives for the industry. This includes the development of real-time process controls to measure and control critical variables such as quench severity, carburizing potential and nitriding potential; development of methods to remotely monitor process variables; and ways to predict future behavior of furnace processes.[2]

Fig. 1. Five steps to optimizing a facility using advanced controls

Developing an Advanced Control and Optimization Strategy	
Step 1	Educate yourself on available technology and tools that can be used to control and optimize manufacturing processes.
Step 2	Define the overall facility objectives for an advanced control system.
Step 3	Conduct a thorough assessment of the entire manufacturing facility.
Step 4	Implement the productivity improvement projects using a tiered approach.
Step 5	Measure and track results.

Five-Step Process to Optimize a Manufacturing Facility

To improve productivity and reduce costs using automation and advanced control requires a strategic view of the issues facing the manufacturing facility. Only by first understanding the big picture can a proper advanced controls strategy be designed. While the literature and market are flooded with products and claims that promise to solve "all of your problems" using state-of-the-art control technology, there is no single, right control solution for all manufacturing facilities. The answer depends on correctly framing the problems and understanding all of the issues that are being faced by a facility.

To facilitate this framework, Figure 1 presents a five-step process for optimizing a facility using automation and advanced controls. Like any other major business decision, developing an advanced control and optimization strategy should be carefully considered, first by understanding available technology and overall facility objectives followed by a thorough assessment of the entire manufacturing operation. This information is critical to determining how to best utilize the company's resources. Only after all of this information has been collected can actual project work begin. Finally, after project completion, results must be tracked and lessons documented for future use.

By following the five steps to developing an advanced control and optimization strategy (Fig. 1) presented in further detail in this article, the chances of reaching true optimal operation are greatly increased.

Step 1 – Awareness and Education

Advanced control technology is not new. The opportunities that exist for advanced control technologies are in its application to new processes and industries. For example, Model Predictive Control (MPC) –

a multivariable control strategy – has been in use for over 20 years in the refining industry with more than 2,000 applications by the year 2000[3]. In the 1990s, this technology was further extended to other industries, including petrochemical, chemical, pulp and paper, and food processing. MPC is currently used by Air Products and Chemicals, Inc. to help control and optimize large complex plants.

Can this technology be used in the heat-treating industry? Because most of the processes used in heat treating are highly complex, the answer is a resounding yes. Currently, there's a gap between state-of-the-art control technology and applications in the heat-treating industry. Three factors explain this gap and why the issues facing the industry today are similar to those faced 20 years ago. They are: availability of low-cost, reliable sensors, which are critical because to control a variable, it must first be reliably and consistently measured in real time; availability of cost-effective process-control solutions; and ability to extend existing control technology to new applications.

In the last five years, there's been major progress in the use of sensor and regulatory control technology in the metal-processing industry, helping to close the gap created by the first two factors. The third factor, extending existing advanced control technology to new applications, can be accomplished with increased awareness and education.

Many of Air Products' operating facilities are large, complex plants featuring nonlinear chemical processes that are run at conservative operating limits since they can be difficult to control. Traditional control strategies do a poor job of managing nonlinearities, interactions or multiple process constraints and typically react to process disturbances after they have already occurred. In addition, traditional controllers do not provide process optimization. Therefore, Air Products uses advanced control techniques like MPC to optimize and reliably control its plants – resulting in substantial, sustainable benefits.

A predictive controller, like MPC, generates new set points for variables based on the anticipated behavior of the process. These controllers have built-in dynamic models of the process and use them to predict what will happen based on past events. In addition, predictive controllers try to react and reject disturbances before the process is affected. MPC takes this a step further, taking into account economic variables, such as the cost of increasing a feed-rate, to determine the optimal operating conditions for the process.

For example, a predictive controller can be applied to a brazing process. Brazing is a heat-treating process that joins metals through the use of a filler metal and heat at a temperature below the melting point of the metals being joined. A successfully brazed joint is often stronger than the base metals being joined. In furnace brazing, the process can be run in a controlled gaseous atmosphere or in an evacuated chamber. Following brazing, the metals are cooled – often in a different zone of the furnace.

A continuous belt furnace is pictured in Figure 2. Typical quality variables for a brazing process include parameters such as joint strength, distortion or an aesthetic parameter[4], all of which are extremely difficult or costly to measure online. Process parameters including furnace temperatures, furnace pressures, atmosphere compositions and furnace dew point are easier to measure and should be used in the control strategy.

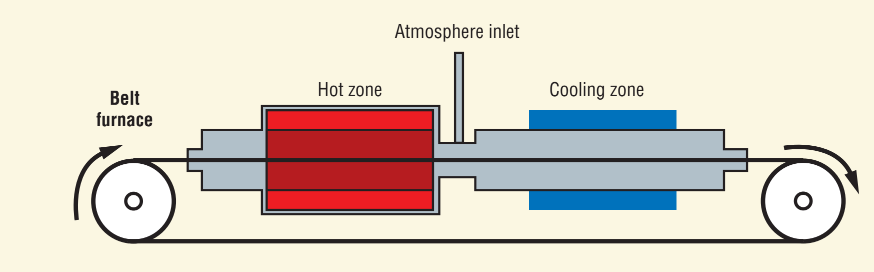

Fig. 2. Continuous furnace brazing process

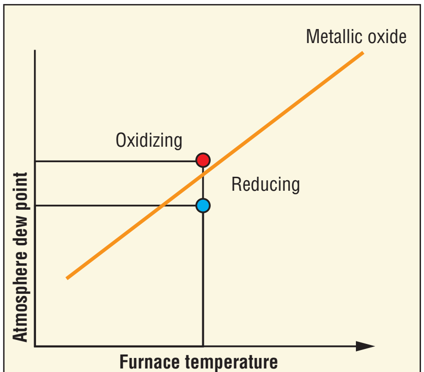

Fig. 3. Oxidation/reduction line for a brazing process

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A multivariable control strategy can provide tremendous benefits to the brazing process. Current fixed operating conditions such as inlet gas flows, furnace temperature set points and belt speed can be used as manipulated variables to maintain a reducing atmosphere in the furnace. Figure 3 illustrates a graph of furnace temperature versus atmosphere dew point for a typical brazing process. For points below the metallic oxide line, the atmosphere is a reducing one. If large variability exists in either the furnace temperature or the atmosphere dew point, it is necessary to operate the furnace well below the oxidation/reduction line. This conservative approach tends to be less efficient and more costly than the optimal operating conditions. A reliable multivariable control strategy will allow manufacturers to run the furnace up against this line, thus operating at the most economically optimum conditions.

For brazing operations, the potential benefits of advanced control and furnace optimization include improved part quality and performance, reduced furnace cycle times, improved oxidation/reduction potential control, reduced atmosphere consumption and early detection of furnace maintenance issues.

Step 2: Overall Facility Objectives

Control-system design is dependent on the overall objectives of the operating facility. Is increased capacity the most important goal? If so, an advanced control strategy may increase operating costs in order to maximize production. Alternatively, perhaps maintaining fixed production at the lowest possible cost is the most important objective. In this case, an advanced control strategy is essential because the controller will need to simultaneously focus on reducing process variability and determining the most economically optimal operating conditions. Traditional control strategies cannot do both. However, if the objective is to maintain consistent process quality on a relatively simple process by reducing variability, a model-based controller may not be necessary.

As noted previously, it is critical to define all of the objectives from an overall facility perspective prior to beginning any project work. This will enable prioritization of projects and provide the best utilization of the facility's available resources.

Step 3: Assessment

Once the facility's objectives and the available control and sensor technology to meet these objectives have been identified, the next step is to conduct a comprehensive productivity assessment of the entire manufacturing operation. A cross-functional team utilizing a defined, rigorous work process should do this. These experts can identify specific improvement possibilities, including potential projects that can result in savings derived from labor reduction, energy reduction, yield/usage improvement, volume increases and quality improvements.

The assessment should concentrate on, but not be limited to, automation and advanced control. The result of the assessment is a detailed list of productivity improvement projects, each with a defined scope and containing estimated costs, benefits and payback. It is critical to assess the entire facility and prioritize the list of possible projects. In many cases, optimizing a single unit operation may cause problems in another part of the facility, resulting in suboptimal operation of the entire plant. In other cases, reducing variability in an upstream process will improve performance in downstream units. The largest gain in productivity may not come from installing the advanced control system but rather from automating difficult operator tasks or in measuring previously unmeasured variables. Projects should be prioritized and implemented in an order that makes the most sense, taking into account the financial and operational objectives of the facility. Such an assessment can result in a concrete implementation plan for overall optimization of the plant in the most efficient way.

Step 4: Implementation

It usually isn't practical or feasible to implement every project identified by an assessment. The projects should be prioritized and implemented in such a way as to begin accruing benefits and, at the same time, laying the foundation for future projects. For example, before implementing an advanced control system, new sensors and analytical equipment should be installed to capture previously unmeasured variables, and a

data-acquisition system should be designed to store the resulting data. Not only will a future advanced control system need this information, major benefits can be realized in many cases simply by viewing and analyzing data that was previously unavailable. With this new data, well-informed decisions can now be made, automated production reports can be designed and the facility is in position to install the next tier of projects to further optimize operations.

An implementation plan will typically begin with the installation of analytical equipment necessary to measure the key process variables. This will be followed by design of a data acquisition and historian system. Computing technology has made it possible to collect, store and mine a tremendous amount of data at low cost. The analysis of this data can result in substantial benefits, even without the installation of new control systems. Real-time process data can be used for production monitoring, optimization of gas consumption, identification of bottlenecks in the process, plant troubleshooting and improved safety using automated alarms. In addition, data acquisition and data analysis are the key enablers of advanced control and optimization of manufacturing processes.

The next phase of projects will involve installation of control hardware and programming of control strategies on individual unit operations. The final phase of projects will then link the individual controllers to optimize the entire facility.

Step 5: Measure Results

Once a productivity improvement project has been implemented, it's important to measure the benefits realized. Monitoring and tracking the results will not only justify the reasons for undertaking the projects and determine if the overall facility goals are being met, but it will also strengthen the case for future project implementations. The data-acquisition system will allow for real-time monitoring of control-system performance and reporting of the realized benefits. Historically, advanced control-system performance tends to diminish and benefits are lost if the system is not actively supported. Therefore, continuous monitoring of performance is needed to determine whether the system is operating as designed.

Finally, it is very important to track and document any lessons learned from project implementations. This valuable information can help future projects be executed more quickly and cost effectively.

Summary

This article proposes a five-step process resulting in a detailed plan to help optimize a heat-treating facility using automation and advanced control. The main points in this process include:

- Education and awareness on automation, sensor and advanced control technology, and how it can be applied to heat-treating processes
- Alignment between the design and implementation of advanced control projects and the overall goals and objectives of the facility
- Thorough assessment of the entire manufacturing operation
- Tiered approach to project implementation
- Measurement of results and documentation of lessons learned

Controls are a critical piece of an optimized operating system. An Air Products' assessment can help you integrate process data with advanced controls to maintain optimization as well as analyze your entire process from leak detection to safety analysis, atmosphere composition, piping, gas use and supply optimization. **IH**

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For more information: Talk to one of our Applications Engineers about a complete assessment or process controls by calling us at 800-654-4567, code 474. Jake Fotopoulos is lead process controls engineer for Air Products and Chemicals, Inc.

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