Real-Time Control and Optimization for Heat Treaters

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More complex process models are being developed to master the heat-treating process and its effect on the parts being treated, and parts manufacturers are becoming more receptive to the idea of having computer-based controls working for them as the demand for tighter process control and monitoring increases.

Time and temperature are critical parameters in any heat treating process. Energy and resources are wasted if a part stays in the furnace too long, and the required mechanical and metallurgical properties may not be achieved if a part spends less than optimal time in the furnace. Previously, there has not been a simple way to measure or track the property transformation within parts during a heat treating operation. Moreover, it requires tedious trial and error methods to determine optimal furnace settings. A new PC-based process control and optimization software, LINE-MOD, promises to change the paradigm of heat treating processes. The software combines advanced modeling with conventional process control and data acquisition to monitor and manage thermal processes more closely than previously possible. The system provides a window to the process, which enables an understanding of the complexities involved in heat treating.

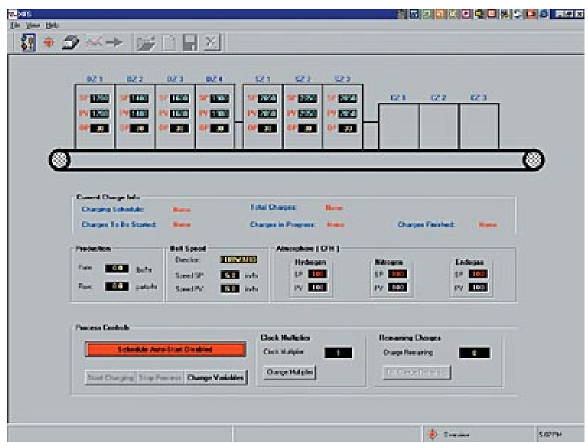

Fig 1 Human machine interface (HMI) for LINEMOD supervisory control and data acquisition (SCADA) system

Why model?

In the past, parts manufacturers tried different methods to determine part properties as the part is heat treated. This information helps process engineers set up furnaces for optimal performance to guarantee production of quality parts with increased efficiency and lower energy consumption. Consider for example a continuous sintering furnace. Green parts traverse the length of the furnace and exit as finished parts. But the operation is complicated. Before placing parts inside the furnace, operators must determine optimum furnace settings (e.g., zone temperatures, belt speed, process gas flow) to ensure proper heat treatment of the parts, including proper part de-lubing in the preheat zones followed by proper sintering.

Is there a way to determine that the parts have attained the correct properties? One approach is to attach a probe to the parts and constantly monitor property changes. This is feasible in a batch furnace with static parts, but presents a challenge with moving parts in a continuous furnace. Moreover, the technique is extremely time consuming and expensive, involving drilling a hole in the part, inserting a probe (e.g., thermocouple) and recording temperature data as the parts move through the furnace. The method provides accurate results, but the set-up time involved makes it impractical each time parts are processed. An alternative method is to use a remote, wireless device to gather temperature data. The technique is satisfactory at lower temperatures, but as the temperature exceeds 2100F (1150C), the size of the insulation needed to protect the sensors makes it unsuitable in certain heating applications. Furthermore, one probe can monitor only one area of the part. It is desirable to know the properties at multiple locations for larger parts, which adds further complexity to the technique.

LINEMOD, a new generation supervisory control and data acquisition (SCADA) system, was designed to meet this need, using a thermal model to predict the real-time part temperatures as they traverse the furnace. The PC-based system is connected to furnace controllers and continuously collects process data (Fig.1). Temperature data is used to generate a boundary condition profile inside the furnace. The system performs mathematical calculations using the boundary conditions to calculate part temperatures at every location inside the furnace. Models also are used to determine furnace settings, wherein an operator selects the part and supplies the desired part temperatures at strategic locations within the furnace. The system then calculates the optimum setting by taking into account the design criteria of the furnace.

Software system description

The software system communicates directly to the furnace controllers to facilitate optimum furnace operation. Three main modules can function together or independently to control and optimize the furnace.

SCADA, Model and Diagnostics, belonging to a Level 2 family of control software, were developed solely for use in heat-treating applications. The system interfaces directly with the existing controllers, or Level 1 system, in a furnace (SLC, PLC, etc.) to upload valuable operational data and download furnace parameters. LINEMOD SCADA is designed not to interfere with the basic controllers of the furnace and, therefore, does not perform any PID functions. Operating set-points can be downloaded from the system, but if the PC system malfunctions, control of the furnace is transferred to the basic controllers.

While a Level 2 system adds flexibility and convenience to a Level 1 system, it does not take control away from the dedicated controllers. It enables centralized monitoring and control of the overall process, allowing the operator to easily view and modify parameters for several processes from one central console on the plant floor. The SCADA system includes Overview, Faceplate, Alarm, Trending and Profile screens.

The Overview screen provides a picture of the overall process. Background graphics, animation and informative displays accurately depict the heat treating process in real time. Set-points (SP) and process variables (PV) for belt speed, temperature, gas flow and dewpoint (if controllers are available) are laid out in a convenient, intuitive format, which allows a quick snapshot. Other screen details include the name of the furnace, number of heating and cooling zones, the current user and their access privileges (read only or change).

The Faceplate screen (Fig. 2) allows a user to modify process parameters to control the furnace. Any controller on the furnace designed for two-way digital communications can be controlled by the system. Sudden temperature changes inside the furnace can adversely affect the life of furnace equipment (muffle and heating elements) and reduce efficiency. To help this situation, the latest software version

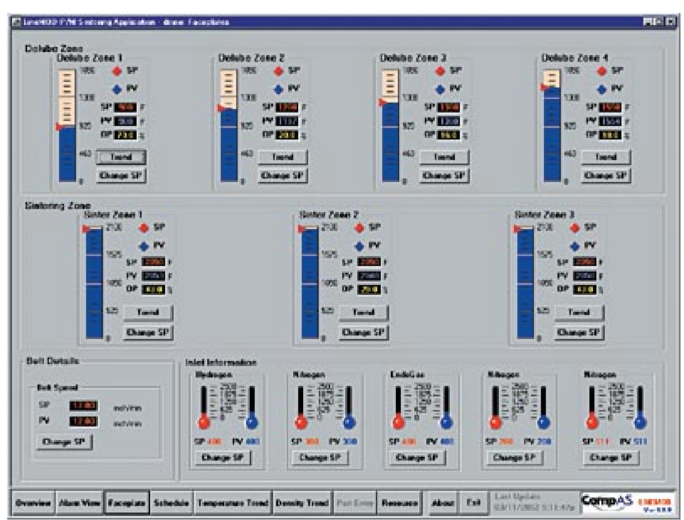

Fig 2 User can control the furnace by modifying process parameters on the Faceplate screen

includes proportional integral derivative (PID) settings in a user-friendly format. Although today's controllers can provide this functionality, it is not easily accessible and in most cases remains unused.

The SCADA system provides process and device alarms for user-defined conditions. The Faceplate screen allows a user to set process bands for acceptable deviation from the target. If the system detects an unplanned change in the process, the user is notified and the condition logged in the software database. The Alarm screen also allows a user to set alarms for zone "overtemps" and other digital devices the system may be connected to. Every alarm event carries details about the user, date, time, and condition that caused the alarm. Any action taken to rectify the condition also is logged in the alarm history.

Trending provides an effective way to monitor SP and PV trends for critical process parameters such as zone temperatures, electrical outputs, gas flow and dew point. A typical trending screen for the sintering application displays temperature and output trends over a specified time interval. Trending facilitates close supervision of critical process parameters and can be customized depending on the application and user requirement.

The Profile screen (Fig. 3) plots a furnace temperature graph (profile) along the length of the furnace. The system reads the real time data from the zone thermocouples located at various locations along the furnace length. These readings are fitted within a curve to generate a continuous profile from one end of the furnace to the other. When coupled with the software's model subsystem, the profile screen displays a part profile together with the furnace profile allowing a user to compare the furnace and the part temperatures in the same overlay.

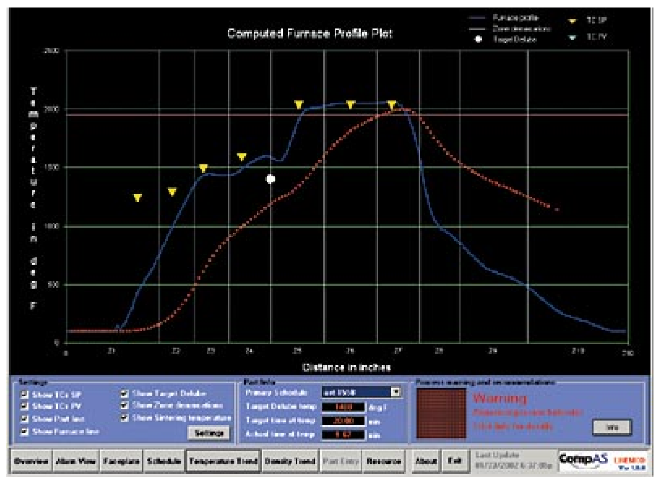

Fig 3 Furnace temperature along the entire length of the furnace is plotted on a Profile screen

Data archiving and report generation

Another important part of the SCADA subsystem is data archiving and generating customized reports to view historical data. SCADA provides an effective way to collect process data that is used as an input for the model subsystem to optimize process parameters. These data also can be transported to other databases, statistical process control (SPC) or spreadsheet applications, such as Microsoft Excel.

Modeling: a powerful tool

Models residing in the control software track the internal conditions of the part as it travels through the furnace and to determine the optimum furnace parameters. The system uses the real-time calculated conditions of the part to fine-tune furnace parameters to attain optimum furnace conditions and obtain quality parts. It is virtually impossible to tell the actual difference in the furnace and part temperatures during an operation, and this system solves the problem by providing a temperature map of each individual part within the furnace at any point in the heating/cooling cycle. The part profile is continuously updated based on the furnace data. Determination of furnace operating parameters can be done on-line; the system calculates the parameters dynamically by feeding all design inputs and operating data to the models. Furnace data used to run the model include material, dimensions of muffle and refractory, zone lengths, and location of thermocouples. Operational data consist of zone temperatures, production rate and gas flow rates. Parts data include shapes, sizes and materials.

There are several modules in the software mathematical model, but the main engine that drives the model is built on transient finite element analysis. In this approach, a set of boundary conditions is applied to the algorithm to obtain the desired results.

Diagnostics

Manufacturers typically collect process data required by their customers. While a majority of companies still use a pen and paper to manually record data, some have adopted electronic data-gathering systems, which allows reviewing process history to determine if something went wrong and what caused it. However, most recorded data still is in a format that presents a huge task for anyone trying to search through it for answers.
LINEMOD diagnostics provides an effective tool to help analyze and interpret data for process trends, carefully scanning incoming data for disturbances. For example, heating element and thermocouple failures often occur without warning in powder-metallurgy sintering furnaces, translating into significant lost production. The diagnostics tool provides a way to predict inevitable heating-element failures allowing ample time to accommodate any changes in the production schedule (Fig. 4).

The system establishes a benchmark from the historical temperature and electrical output values for each furnace zone and compares incoming data to this acceptable range of deviation. As a heating element degrades, it draws higher electrical current to achieve the same setpoint temperature, which causes the output to remain outside the acceptable range. A condition where zone output constantly remains over the acceptable level of output deviation is characterized as heating-element degradation.

Fig 4 Imminent furnace heating-element failure is predictable using control software diagnostics

The above diagnosis is based on two assumptions. One, there is no change in production rate; that is, an increase in belt speed or part charge weight results in an increase in production rate causing the output to increase beyond normal levels. The production function is given by belt velocity times charge weight (collective weight of all the pieces in a tray/batch). Two, there is no change in setpoints; an increase in setpoint value for zone temperature results in the heating element drawing more current, which could be misinterpreted by the system as a failing heating element. When heating element degradation is detected, a warning sign appears and remains until the condition is rectified.

A similar principle applies for detecting failing thermocouples, except that the PV drops or increases suddenly causing a deviation much greater in magnitude than in a heating element failure. To rule out a possible shutdown by the operator, where all zones will cool down at a similar rate, the temperature read out in one heat zone is compared with read outs in other heat zones. If the temperature gradient drastically deviates beyond the prescribed range of operation, the condition is diagnosed as a thermocouple failure.

System communication

The control system resides on a standard PC running Windows-based operating systems such as Microsoft Windows NT 4.0 Work-station (preferably) or higher (Fig.5). The computer is connected to Level 1 controlling and monitoring devices such as single loop controllers (SLCs), programmable logic controllers (PLCs), belt-speed controllers, proximity/motion sensors and analyzers/monitors (gas) on an operating furnace. Communication is established using device-dependent interface protocols including OPC standards, Modbus RTU, Modbus TCP and Ethernet. The control system can connect to most major brand name controllers and sensors. It does not replace dedicated controllers, but instead, it augments existing control systems by transferring critical process data from different controllers and monitors on the furnace to a centralized system.

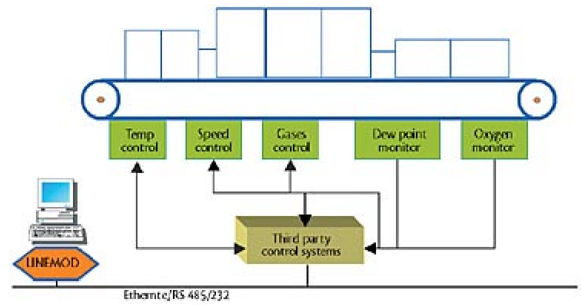

Fig 5 Schematic of system communication

Client/server architecture

The software is designed based on client/server architecture that has become a standard in network computing; the client makes a service request, and the server performs the computing to fulfill the request. This architecture reduces network traffic by providing a query response rather than total file transfer. It improves multiuser updating through a graphical-user-interface front end to a shared database. The server (plant floor application) directly communicates with the furnace controllers, collects and stores data in the database. A client (desktop application) reads the data from the database and displays it in a user-friendly graphical user interface (GUI) on multiple computers, which may be located in various geographical locations.

Internet application

The Internet is playing a big role in shaping the future of worldwide manufacturing businesses, such as petroleum, metals, pulp and paper, and glass industries, which realize the value of automated data acquisition. The Internet has taken this to the next level, enabling sharing of plant floor data across various divisions to improve and streamline processes and implement uniform operations. The heat treating industry has been slow to adopt this technology but is "gearing up" to embrace it. eProcessView CompAS's eProcessView is a web application that provides remote users with viewing (read-only) access to furnace process data using any standard web-enabled computer (Fig. 6). It connects the factory floor to the world and brings the power of remote diagnostics and collective troubleshooting to the heat treating industry. The application integrates seamlessly with the software control system at a plant and transfers process

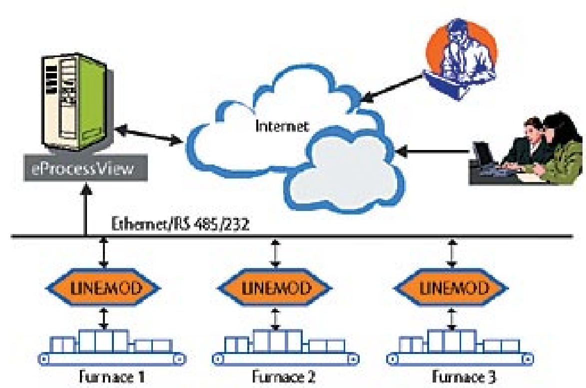

Fig 6 eProcessView architecture provides remote user with viewing access to furnace process data and product data to a central server at CompAS. An authorized user can view the process live from any location, on a standard web browser.

To use eProcessView, both the client and server must be connected to the Internet. The client can use any type of Internet connection including a dial up modem, but the server preferably should be on a dedicated Internet connection such as a LAN (local area network), WAN (wide area network) or DSL. Also, the client PC must be equipped with a standard web browser. No other software, driver or application is required on the client PC.

Most companies support some type of computer network, and the control system server is connected to the existing Intranet/Extranet just like any other computer. Once on the network, the server and eProcessView communicate with each other via a port on the company's LAN. The allocated port sends data from the plant floor to the eProcessView server. Any type of service request arising from a computer on the network (client) is serviced using the specific port associated with that particular application (in this case eProcessView). User access to the server to view the real time process is granted via an assigned username and password. Secure architecture The eProcessView incorporates several security features to address the issue of Internet security. The web server sits between the client and the server on the plant floor forming a pass that can be closed should the application detect any foreign intrusion. The system uses proprietary tools coupled with Microsoft Windows NT's security to manage and authenticate users.

User benefits

Real-time monitoring: eProcessView allows authorized users to view, analyze and manage the thermal process anytime, anywhere using a standard web browser. A faceplate screen provides a real-time picture of temperature, belt speed, gas flow and dew-point variables for all preheat, high heat and cooling zones on the furnace. The profile screen displays a time versus temperature graph (profile) for the furnace and parts and also provides time at temperature, which denotes the amount of time parts should either be at or over the target temperature to develop the desired hardness, strength and other metallurgical properties.

Joint problem solving and uniform operations: eProcess-View collects information from multiple sources on the plant floor. Raw material suppliers, equipment OEMs and heat treaters can collaborate to solve process problems, reducing the time required to resolve quality issues. For companies having large-scale operations, especially in different locations, the system provides the power to view on a desktop PC disparate processes simultaneously. Company personnel can review and analyze processes from any location and implement uniform operations. Small to medium-sized heat treating operations can easily share process information with off-site consultants and can outsource process data storage and analysis needs, allowing them to concentrate on their core business.

Secure data warehouse: Because lost data can mean delayed production or other problems, real-time data from the plant floor is stored in the eProcessView web server at a secure location. If an event on the plant floor makes data in LINEMOD unusable, eProcess-View can be used as a backup to retrieve process information.

Extensibility and ease of use: The Internet-based architecture allows new processes to be added as easily as the number of users viewing them. Thin client technology means that clients do not need extensive hardware to run the application, because all information is managed on the server. The client just needs a web browser and access to the Internet. The only maintenance required is on the server, which is managed by the company hosting the web application. Users can quickly learn to use the software because most of the application tools are extensions of web tools that come standard on a browser, saving a lot of the costs associated with training and implementing a process management solution.

Companies rely on accurate process information that can be disseminated and used effectively throughout the enterprise. The Internet application makes it possible to achieve these goals without incurring huge costs on software and hardware and allows companies to easily expand according to their changing needs.

Acknowledgement

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