COLLABORATIVE MONITORING AND CONTROL OF SINTERING USING A WEB-BASED TECHNOLOGY

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ABSTRACT

With an increase in the demand for complex powder metallurgy parts, concerns and challenges associated with sintering and related processes are rising. Also, quests for process knowledge, failure diagnosis and operational trends are leading to the faster acquisition of increasing amounts of real-time and archived process data. Due to this, plant managers and process engineers are expending extensive resources to monitor and control their sintering operations in order to achieve and maintain the highest product quality with optimum productivity. This paper describes a secure web-based technique that enables remote accessibility and monitoring of real-time process data, thereby facilitating collective problem solving, joint troubleshooting, remote process viewing and analysis. Implementation of this technology helps improve the overall productivity of the sintering process by networking internal sintering operations with external supporting resources.

INTRODUCTION

Powder metallurgy (P/M) parts manufacturers are challenged continually to meet customer demands for lower price and faster delivery of the finished product. Meeting these challenges gives P/M companies a competitive edge. This challenge pushes process engineers to the point at which constant monitoring of a sintering operation becomes imperative.

At facilities with furnaces treating parts at temperatures over 1000 °F (537° C), it is important that the process be monitored closely. It should be understood that the rigors of this process demand vigilance and strict code adherence - at all times. Control of variable-sensitive manufacturing processes requires ongoing surveillance and continual correction maintenance. Material variability, equipment changes, process drift, a change in operator, and other unforeseen variables affect directly properties of the finished product. A cumulative effect of these factors can result in unacceptable finished parts. To safeguard against such rejections a program of continual real-time monitoring and review of product attributes is necessary to maintain desired properties within acceptable ranges.

Understandably, the nature of this around-the-clock monitoring is wearisome, mostly redundant and an unrewarding chore. In a well-controlled and established process, changes may be needed only infrequently. Most of the time the monitoring activity indicates that no corrective action is required, adding no significant value. Historically, it is evident that most statistical process control tools have failed due to this reason but there is one clear truth: however distasteful the nature of the work, remains a necessity.

An automated monitoring system with readily accessible data and having no geographical limitations presents intriguing prospects to ease this otherwise intimidating task. Ideally, such a system should constantly, and consistently, track process parameters and determine the changes required. To further the concept, it should extend to calculating changes recommended and evaluating the effect of such changes. Personal action by the process manager would be required only when the surveillance system indicated the need for attention.

The scope of this system can be extended to remote control, however this study is confined to the monitoring component of the system. This paper will review the concept of a secure web-based technique that enables remote accessibility and monitoring of real-time process data, thereby facilitating collective problem solving, joint troubleshooting, remote process viewing and analysis.

PROCESS/APPLICATION CHALLENGES AND OBJECTIVES

Sintering is a complex process in the production of (P/M) parts. Important part properties such as density, hardness and strength change during the sintering process. Since the final mechanical properties of the part are direct functions of the heating environment in the sintering furnace, monitoring and controlling these parameters are important and essential.

The internet system has been implemented at Allegheny Powder Metallurgy, Inc., (APM) at Falls Creek, PA and at other sintering facilities. At APM, one of the primary challenges is to achieve acceptable quality of the parts to be sintered. Making sure the parts are delubed adequately before sintering is a critical issue. Another challenge is to determine the appropriate belt speed for the part to insure adequate time at temperature. At APM, to avoid fine-tuning of belt speeds and to monitor closely the parts being processed (given their various dimensions and shapes), the favored processing procedure is to set the belt speed at 6 inches/minute. This results in some parts being processed satisfactorily while others are over processed, meaning the process is not optimized, leading to a loss in productivity and increased energy consumption.

Other critical issues: Thermocouples and heating elements often fail without any warning. For a parts manufacturer this translates into hours and in some cases days of lost production. While heating element failures are inevitable, the ability to predict them ahead of time, and to detect the problem as it occurs, gives ample opportunity to accommodate any changes in the production schedule.

Another critical factor in the efficient performance and functioning of a furnace is fine-tuning of the Proportional, Integral and Derivative (PID) parameters within the temperature controllers. The objective of good temperature control is to attain a steady state condition. This is accomplished by setting correctly the PID parameters in the controllers. At APM, the PID settings in one of the zone controllers were not set correctly resulting in fluctuations in zone temperature. Due to this phenomenon, a steady-state temperature was never attained and the parts did not see a constant temperature. This situation affects adversely both the delubing and sintering processes and must be prevented in achieving quality parts. It also wastes energy and reduces the life of both globar and muffle.

Proposed Solution and Its Functionality

Solution: - To monitor closely and remotely, the sintering process internally from the office of a process engineer a web application system has been installed at APM. The system was installed with the objective of monitoring closely:

- Sintering time and temperature
- Completion of delube process
- Incipient failure of heating elements (Globar) and thermocouples.
- Display alarms for PID tuning.

Internet Application: The internet is playing a major role in shaping the future of worldwide manufacturing businesses, such as petroleum, metals, pulp and paper, and the glass industries, which recognize the value of automated data acquisition. Similarly, we have observed that several P/M facilities have adopted applications such as PCAnywhere and other similar software systems, which allow for remote access. The internet has taken this to the next level enabling the sharing of plant floor data across various divisions to improve and streamline processes, and implement uniform operations.

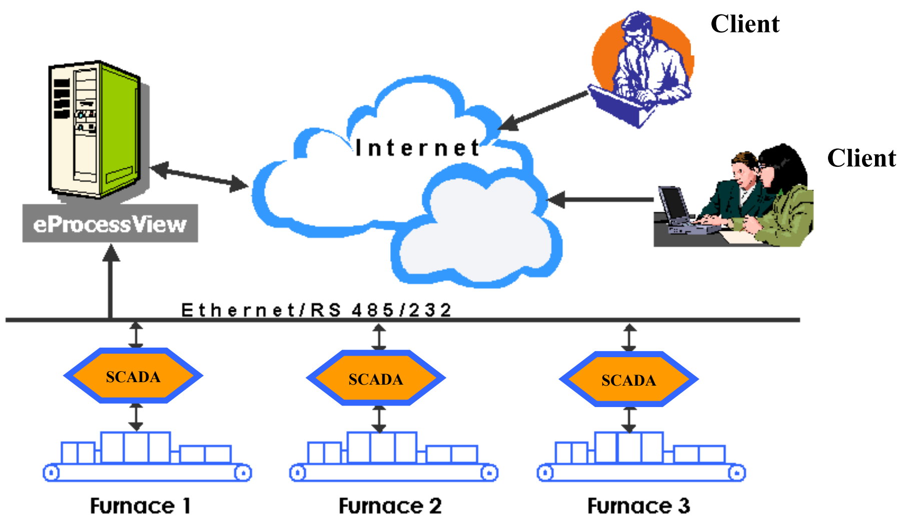

Figure 1. Web application architecture provides remote user with viewing access to furnace process data.

Web Application and Its Functionality: eProcessView is a web application that provides remote users with viewing (read-only) access to process data using any standard web-enabled computer. It connects the factory floor to the world and brings the power of remote diagnostics and collective troubleshooting to the heat treating industry.

eProcessView integrates seamlessly with existing Supervisory Control and Data Acquisition (SCADA) systems and transfers process and product data from the SCADA system to a central server. An authorized user can view the process live from any location, on a standard web browser (Figure 1).

Before continuing it is important to understand the functionality of the software system used in this study.

System Communication: The SCADA system is PC-based software that communicates directly to the furnace controllers to facilitate optimum furnace operation. The system resides on a standard PC running Windows-based operating system such as a Microsoft Windows NT 4.0 Workstation (preferably) or higher. As shown in Figure 2, 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. The SCADA system can connect to most major brand name controllers and sensors. It does not replace dedicated controllers, instead it augments existing control systems by transferring critical process data (from different controllers and monitors on the furnace) to a centralized system.

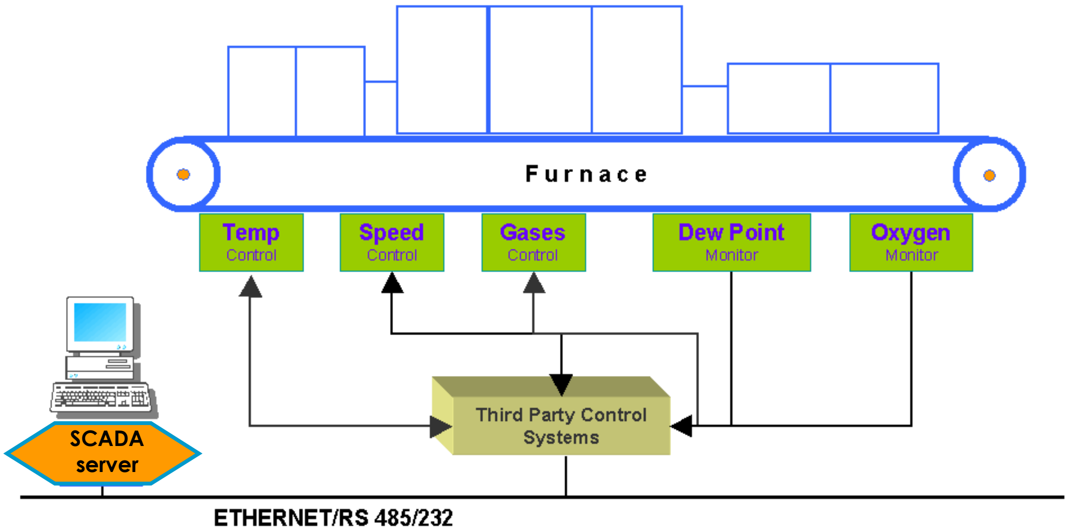

Figure 2. Schematic of communication for the SCADA system.

Client/Server Architecture: The SCADA software design is based on a client/server architecture. 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 multi user updating through a front-end graphical-user-interface to a shared database.

In the system's client/server configuration, the SCADA server (plant floor application) communicates directly with the furnace controllers, and gathers and stores data in the database. A SCADA client (desktop application) makes a request to the server for data from the database and then displays it in a user-friendly graphical user interface. A server can provide data to multiple client computers, which may be located in various geographical locations.

eProcessView requires both the client and the SCADA server to be connected to the internet. While the client can use any type of internet communication structure including a dial up modem, it is preferred that the Server be on a dedicated internet communication structure such as a LAN (local area network), WAN (Wide Area Network) or DSL (Digital Subscriber Line). Also the client PC must be equipped with a standard web browser such as Microsoft's internet Explorer or Netscape's Navigator, preferably version 4.0 or higher. No other software is required on the client's computer.

Most of the companies support some type of computer network. The system's server is connected to the existing intranet/extranet like any other computer. Once on the network, the server and eProcessView communicate with each other via a port.

A port can be thought of as a "Gateway" or a channel that can be associated with a specific service running on a network Server. Any company subscribing to the eProcessView service provides an available port number on their LAN. The port allocated is used to send 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 the particular application, in this case eProcessView.

In web application programming, a port is a logical connection. A client's program communicates through this port with a server program in a network using the internet's TCP/IP protocol. Higher-level applications using TCP/IP such as the web protocol, hypertext transfer protocol, have ports with pre-assigned numbers. These are known as "well-known" ports that have been assigned by the Internet Assigned Numbers Authority (IANA).

Other application processes are given port numbers dynamically for each connection. When a service (server program) is started, it is said to bind to its designated port number. When a client program wants to use the server, it must also request to bind to the designated port number.

Port numbers are from 0 to 65536. Ports 0 to 1024 are reserved for use by certain privileged services. For the HTTP service, port 80 is defined as default and it does not have to be specified in the Uniform Resource Locator (URL).

A user desiring to view the real time process supplies an assigned username and password to gain access to the eProcessView server.

Secure Architecture

Since internet security is of growing concern among users as well as network administrators, all aspects of data security have assumed increasing attention as a result of the internet's open design and increased usage. This web application incorporates several security features to address this issue. The web server sits between the client and the SCADA 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.

The internet technology used in hosting this web site is based on standard TCP/IP protocol. TCP/IP (Transmission Control Protocol/Internet Protocol) is the basic communication language or protocol of the internet. It can also be used as a communications protocol in a private network (either an intranet or an extranet). When set up with direct access to the internet, the computer is given a copy of the TCP/IP program.

TCP/IP uses the client/server model of communication in which a computer user (client) makes a request and is provided a service (such as sending a web page) by another computer (server) in the network. TCP/IP communication is primarily point-to-point, meaning each communication is from one point (or host computer) in the network to another point or host computer.

System Implementation

The web system installed on the furnace at APM has nine process zones as shown in Figure 3. Three preheat zones (delube), three high-heat (sintering) zones, and three cooling zones constitute these nine zones. The dimensions of the zones are listed in Table 1.

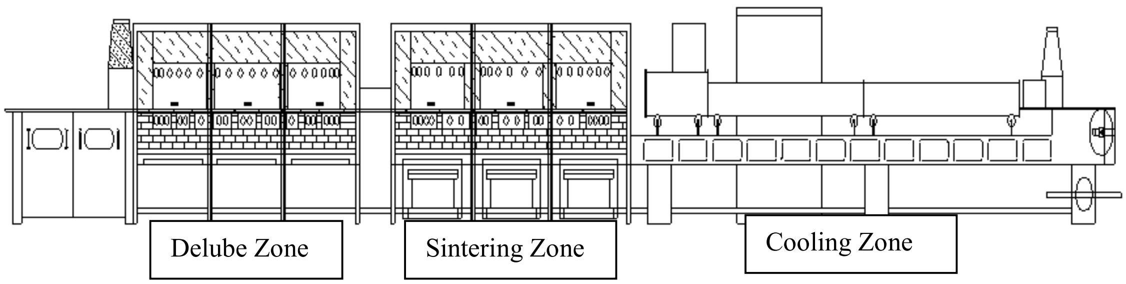

Figure 3: Furnace-schematic

Table I: Dimensions of Furnace

Zone type	Zone Length
Delube	168 inches
Sintering	168 inches
Cooling	288 inches

The LINEMOD[1] SCADA system monitors critical part parameters such as the delube temperature and the sintering time at temperature, as parts of different shapes and dimensions are being processed.

The web application eProcessView has two main screens:

- Thermal Profile View
- Monitoring and Diagnostics View

The thermal profile view screen is a window to the process. By looking at this screen the viewer can tell what is going on inside the parts. The monitoring and diagnostics screen allows the viewer to see the status of the heating zones along with the alarm conditions indicating any impending failures. Details are discussed in subsequent sections, with two examples.

[1] LINEMOD is a SCADA system marketed by CompAS Controls, Inc.

Process Analysis and Diagnostics:

The screen in Figure 4 shows the muffle temperature and average part temperature along the furnace length. Here a flange shaped part having the dimensions and properties listed in Table II is undergoing sintering.

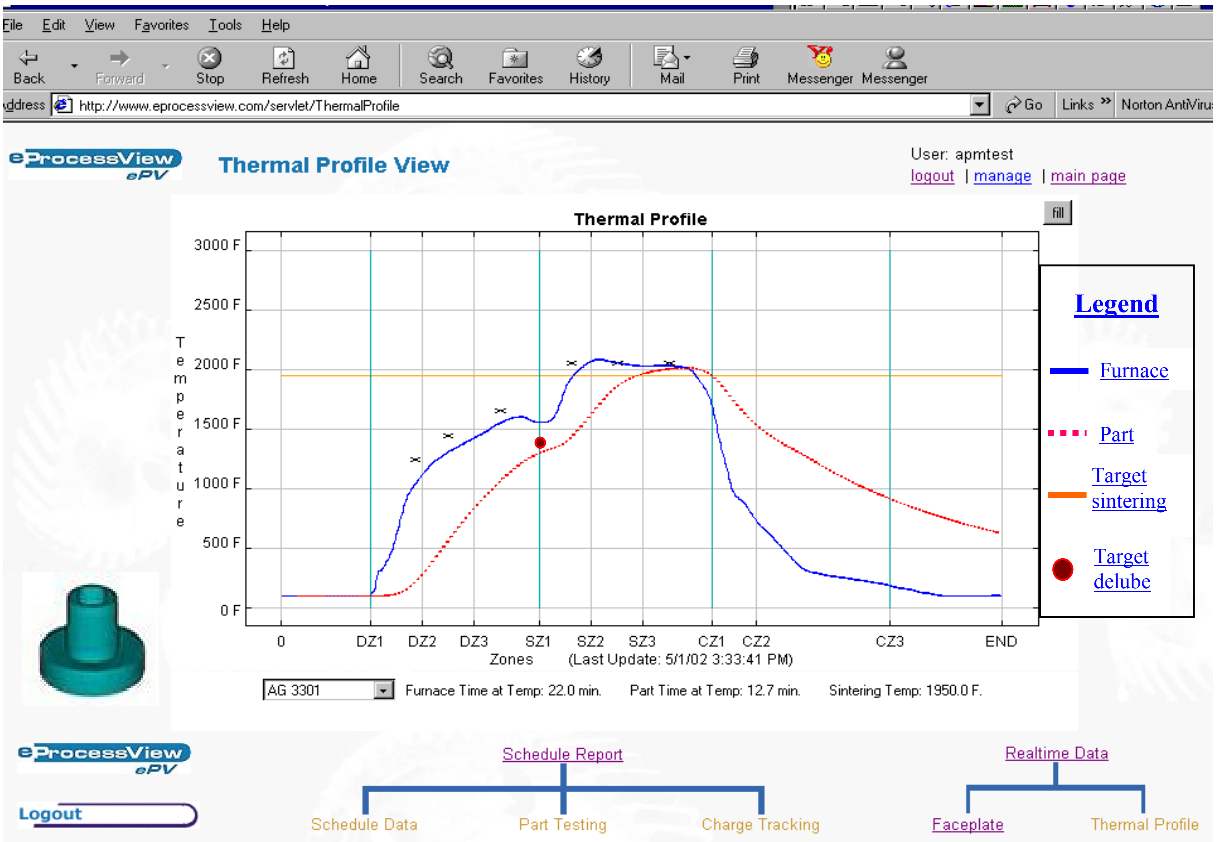

Figure 4: Thermal profile of furnace and flange shaped part.

The screen display includes the furnace temperature profile, which is delineated with a **blue** line while the part temperature is shown with a **red** dotted line. The "**x**" marks indicate the temperature in the preheat and high heat zones, which are labeled DZ1, DZ2 and DZ3 for the three delube zones. The high heat zones are labeled SZ1, SZ2 and SZ3, corresponding to the three sintering zones. The cooling zones are labeled CZ1, CZ2 and CZ3.

Table II: Part Dimensions and Material Properties. All dimensions are in inches.

ID	OD	FLANGE OD	BODY OD	OAL	SMALL FLANGE THICKNESS	FLANGE THICKNESS
0.4685	3.515	3.495	1.758	1.438	0.715	0.575
0.4715	3.526	3.505	1.767	1.453	0.725	0.585

MATERIAL: F-0008	**DENSITY:** 6.85 / 6.95 g/cm3	**VOLUME:** 104.52 g/cc	**WEIGHT / piece:** 720.0 / 726.0 gms

The horizontal **orange** line is the target sintering temperature, which is usually set to 1950º F (1065º C). Time at temperature (t@T) is defined as the time spent by the part above the target sintering temperature, which is usually considered to be 20 min. Compared to the target, the actual sintering t@T is 12.7 min.

The system indicates that parts did not achieve the target t@T of 20 min. This information is critical because parts with different shapes and dimensions will have different values of t@T. If the target t@T is not achieved, the system recommends an adjustment in belt speed.

A **red** spot in the center of the screen indicates the target delube temperature of 1400 º F (760º C). The delube process in any sintering application is critical. In Figure 4 the system determines that the part did not attain the recommended delube temperature.

The screen in Figure 5 displays the processing of a different part (dimensions and properties shown in Table III) with the same processing parameters. The system shows that the part has attained a different t@T, due to its shape and dimensions.

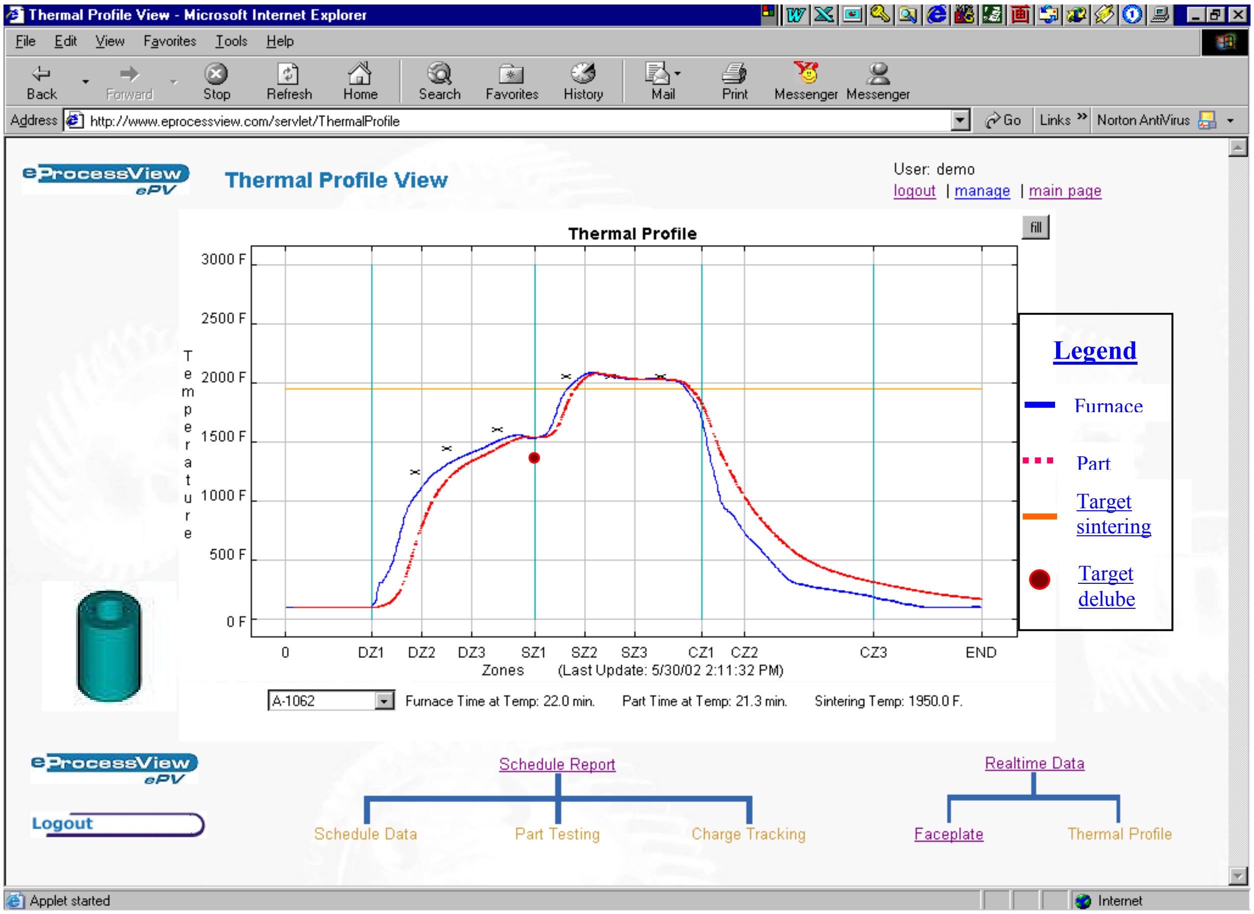

Figure 5: Thermal profile of furnace and a regular bushing-shaped part.

This new part attains a t@T of 22 min at a belt speed of 6 in/min. Compared to the previous part, this part is smaller with minimal geometrical complexity. This results in parts being over-delubed and over-sintered.

Table 3: Dimensions and material properties of the bushing part. All dimensions are in inches.

Inner diameter	Outer diameter	Overall length
0.510	0.980	0.550
0.520	1.020	0.560

MATERIAL: F-0008	**DENSITY:** 6.6 / 6.7 g/cm3	**VOLUME:** 5.251 g/cc	**WEIGHT / PC:** 34.7 / 35.2 gms

Process Monitoring and Instrument/Device Diagnostics:

Figure 6, displays the eProcessView's "Monitoring and Diagnostics" screen. The screen is displayed when users log in securely to the web site, and to their specific furnace-process viewing area. The screen allows the user to view the overall process conditions on a single screen. It also allows the user to view the status of some of the critical instruments and devices.

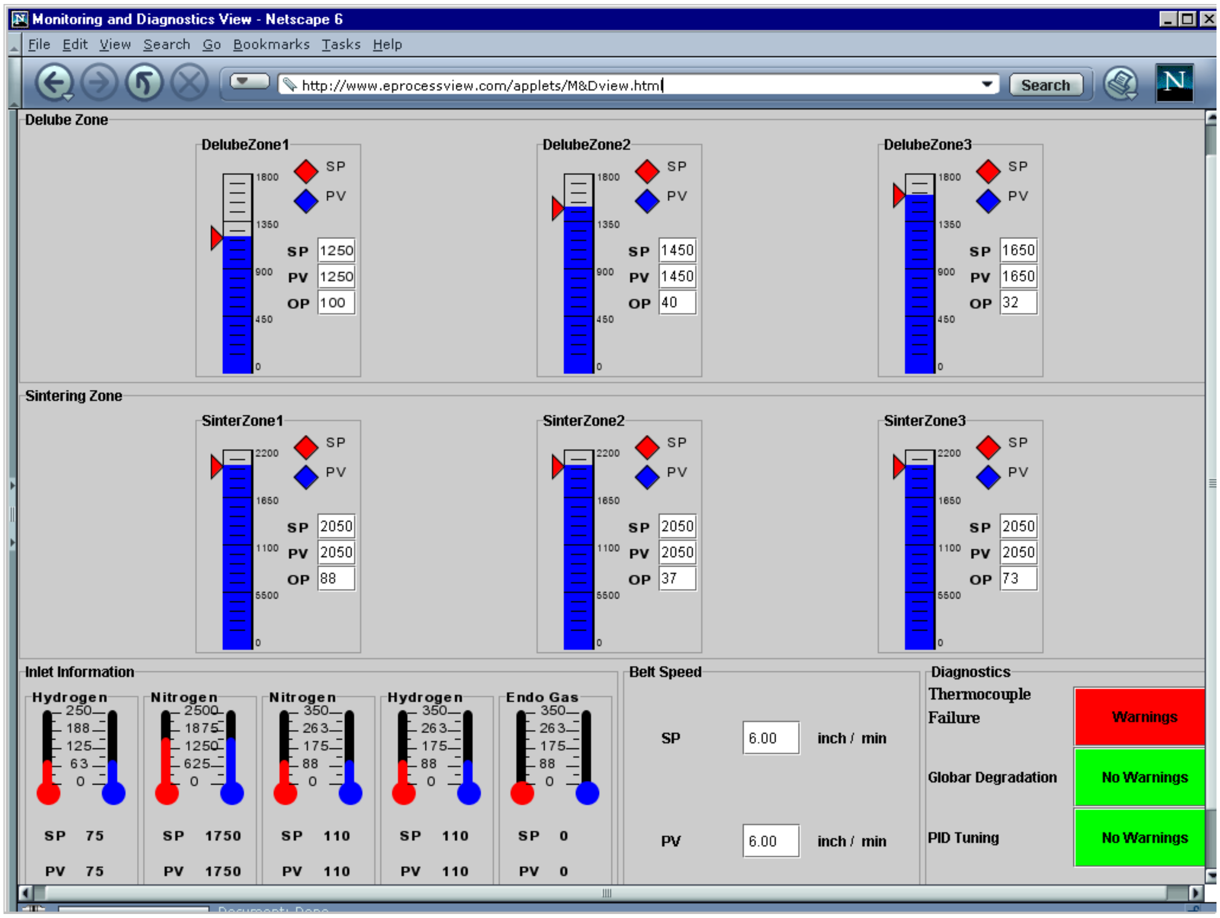

Figure 6: "Diagnostics screen' displaying critical process-related corrective recommendations A thermocouple failure warning is displayed.

The top section of the screen displays the controller parameters of the six heating zones. They are Setpoint (SP), Process Variable (PV), and Output (OP). The lower-left side of the screen displays the status of all the gas flow meters. The current belt speed is displayed at the bottom center. The process diagnostics are displayed in the lower right hand corner. A flashing red button suggests an irregularity in the equipment. When the warning button is clicked, a message is displayed delineating the zone where the failure occurred, and the nature of the failure.

Thermocouple Failure:

Thermocouples have a finite life span. Thermocouples in a sintering furnace usually fail every three to six months. It is important to detect the failure since a faulty thermocouple will not allow the controllers to maintain the desired zone temperatures. Figure 8, displays a thermocouple failure warning; this is the part of the screen shown in Figure 6.

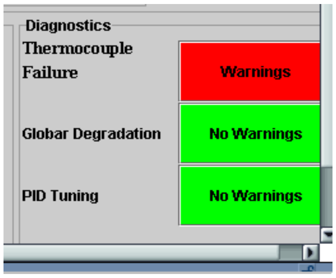

Figure 8: "Diagnostics screen" displaying thermocouple failure

Thermocouple Failure Detection Logic:

In this case the temperature indicated by the thermocouple drops or rises suddenly, causing a drastic fluctuation shown in Figure 7. The temperature read out in one heat zone is compared against the read outs in its adjacent zones. If the temperature gradient deviates drastically beyond the preset range of operation, the condition is diagnosed as a thermocouple failure.

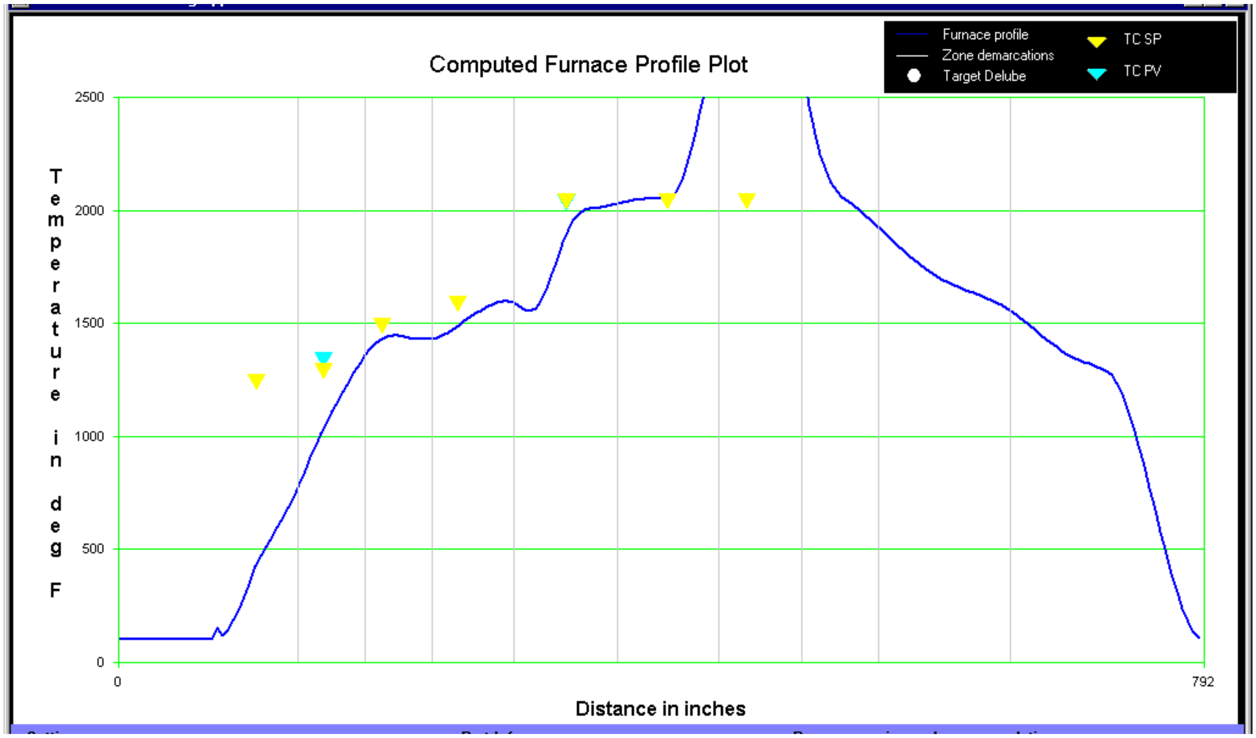

Figure 7: Thermocouple failure in sintering zone # 3.

Globar Degradation:

Globars degrade with time and this results in drawing of excessive electric power. Moreover, this could lead to a desired temperature not being attained. This condition may result in under-heating of the parts and needs to be detected. Figure 9 displays a globar degradation warning.

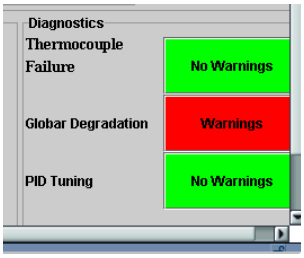

Figure 9: Globar failure

Globar Degradation Detection Logic:

Figure 10 illustrates the logic of capturing globar degradation. Continuous communication with the temperature controllers gives a real-time reading of the power output in every zone. In this case it is evident that the output has been rising gradually over a period of time, resulting in the drawing of extra current, hence power, to compensate for the degradation.

The diagnosis cited is based on two key assumptions. There is no change in production rate; an increase in belt speed or the weight of the parts in a charge will result in an increase in production rate causing the output to rise beyond normal levels. Where the production function can be explained as: production = belt speed x charge weight (collective weight of all the pieces in a tray/batch).

There is no change in setpoints; an increase in setpoint value for a zone temperature will result 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.

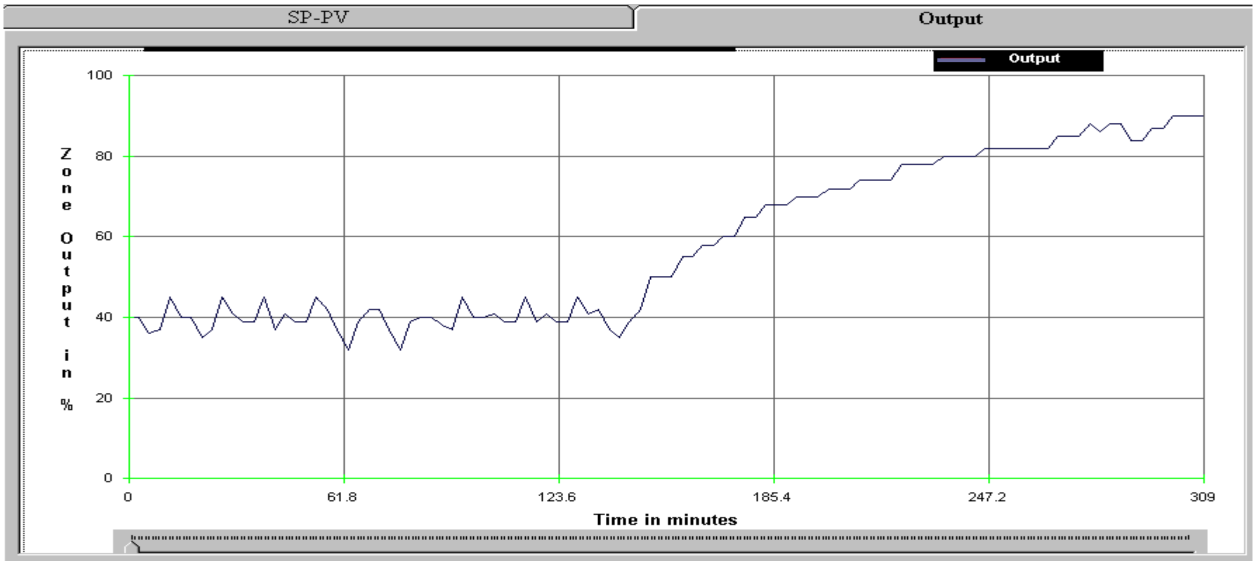

Figure 10: Real-time "Trending screen" displaying output rising over a period of time

Out of Tune PIDs[2]:

Achieving a steady state condition in each heating zone is essential for energy efficiency and the life of the furnace components. Steady state is attainable by tuning properly the PID settings. PID settings go "out of tune" with time and therefore the detection of this condition is imperative. Figure 11 displays an out-of-tune PID warning.

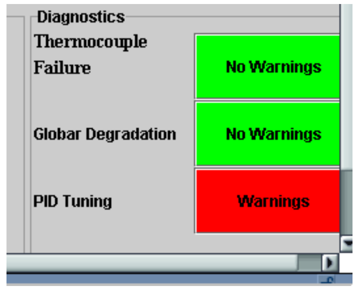

Figure 11: PID tuning warning

PID Tuning Detection Logic:

An "out-of-tune" PID setting is indicated by fluctuations in the zone temperature. Figure 12 illustrates an "out-of-tune" PID condition.

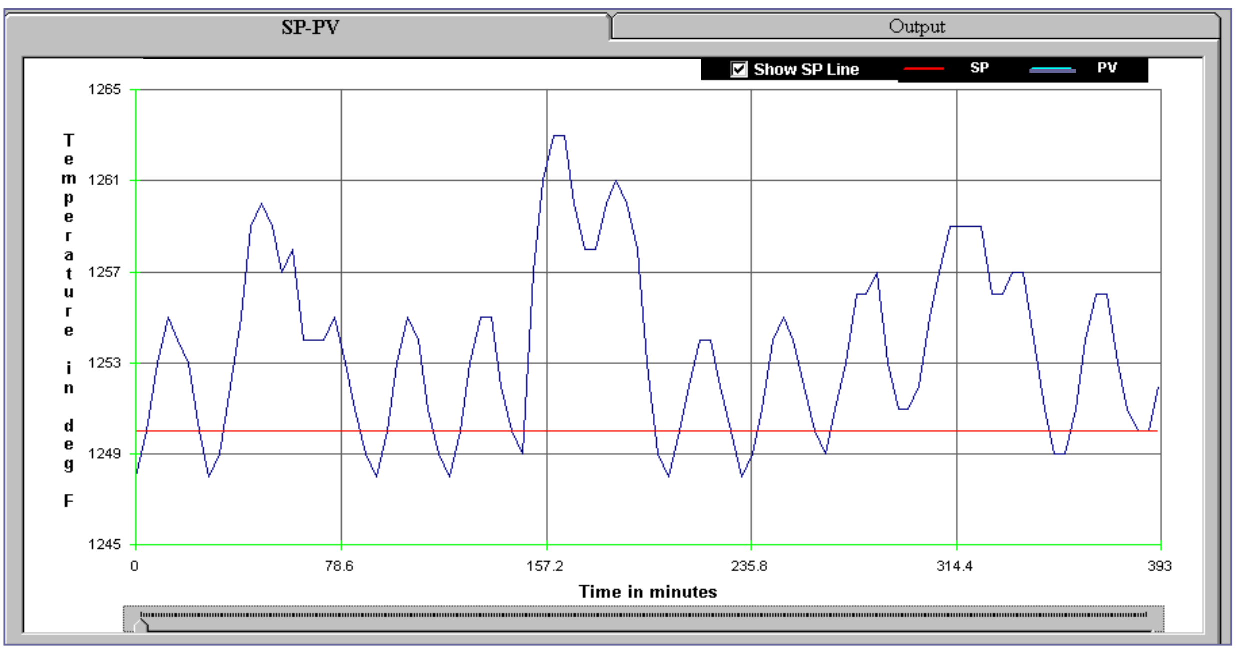

Figure 12: Real-time 'Trending screen" displaying setpoint and process variable deviation

In Figure 12, the red line indicates the setpoint (SP) for preheat Zone1, which is set at 1250° F (676° C). The blue line indicates the process variable (PV), which fluctuates from 1247° F (675° C) through 1263° F (683° C).

The "out-of-tune" condition of PID is also evident in the output trending screen, as shown in Figure 13. In this case, the controller for the zone fluctuates beyond the acceptable window of 30%. An algorithm captures this situation, thus alerting the system with a warning displaying "out-of-tune" PID settings.

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[2] PID = Proportional Integral and Derivative.

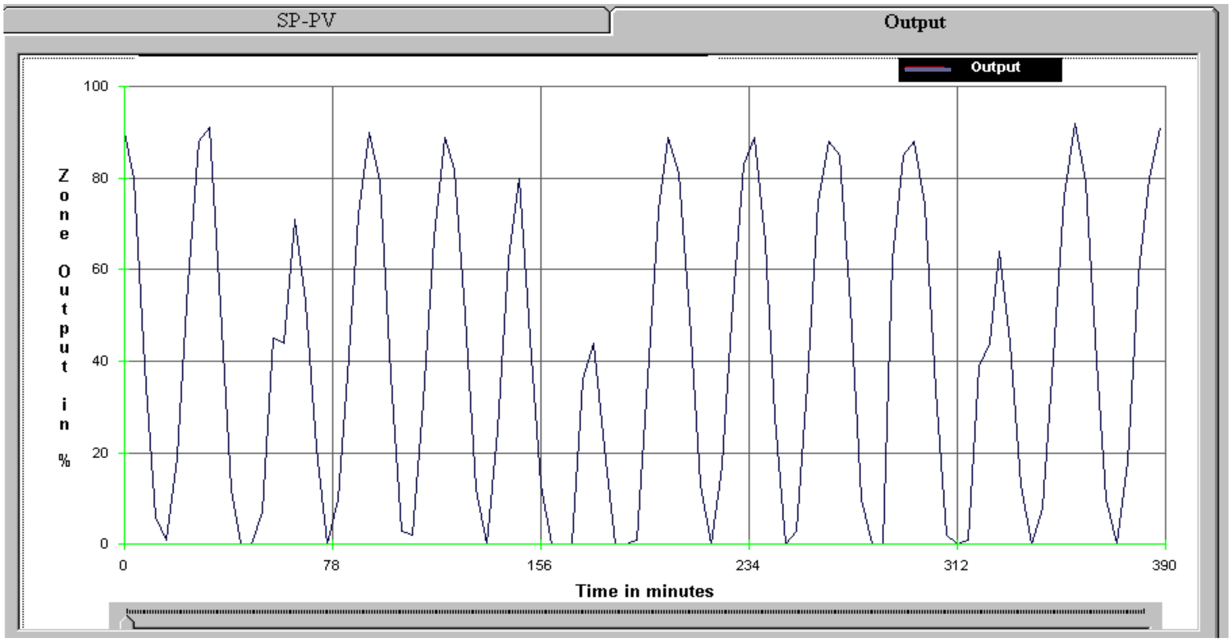

Figure 13: Real-time "Trending screen" displaying output deviation per zone

Figure 14 displays a real-time trend of the output readings after the PID parameters have been tuned. It is evident that the deviation bandwidth has been reduced and this results in more efficient firing of the globars. These actions also led to a reduced deviation of PV from the SP in the zone.

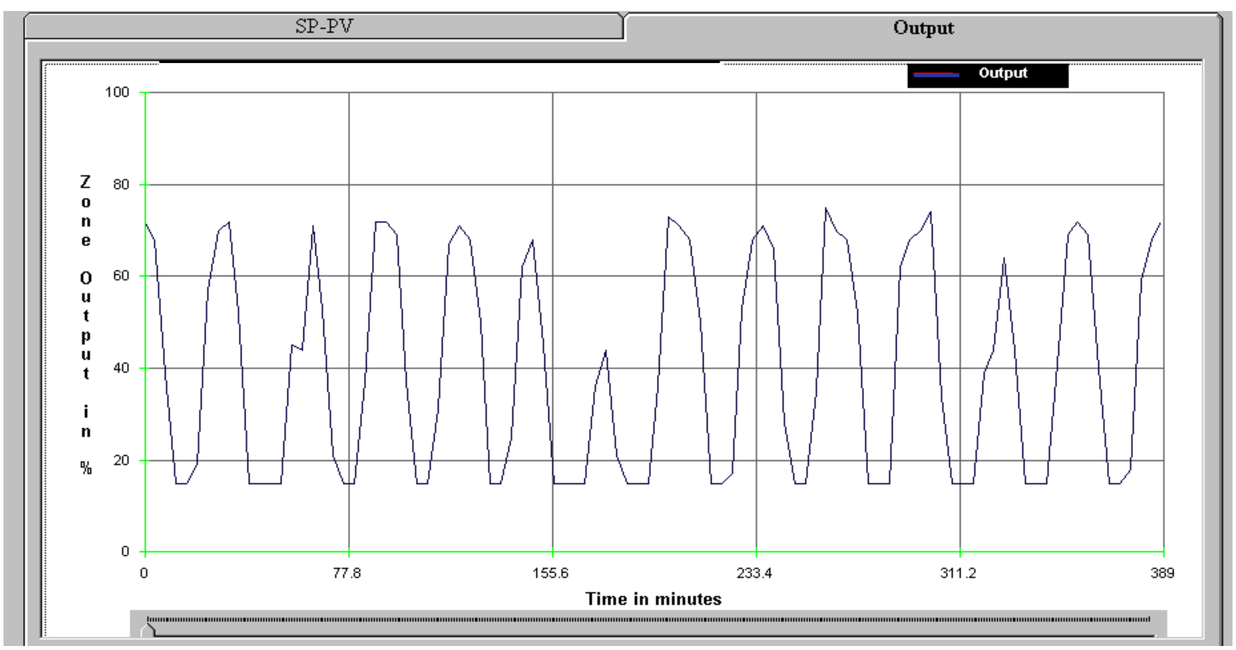

Figure 14: Post tuning "Real-time Trending screen" displaying setpoint and process variable deviation.

CONCLUSION

The results of this study have shown that close monitoring of real-time process information is the key in producing quality parts. Extensive process data are generated in a production environment. The goal is to convert this data into information, which then can be analyzed by all the supply chain partners for joint monitoring and trouble shooting. Additionally, sophisticated software with an integrated knowledge base can synthesize this data to facilitate equipment and process diagnosis. Monitoring a process closely and identifying impending failures increases productivity, reduces downtime, and improves yields.

The web-based monitoring system aims at breaking the barrier of accessibility to information. This is achieved by having all process data (in the form of real-time information) at the fingertips of all those who are involved in the production of quality products, in this case sintered parts.

Security is an important concern when production information is shared outside the manufacturing premises. Strict security measures are followed in hosting the web site wherein all proprietary information relating to companies is kept confidential on the world wide web. State-of-the-art web servers are used in the fast serving of information, and in backing up data reliably.

ACKNOWLEDGMENTS

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