Top 10 tips to improve efficiency in heat treatment processes

Material Processing Knowledge Series

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Eurotherm®

Executive Summary

Heat treatment processes involve high energy usage and compliance to strict industrial regulations. Poor control of the process can lead to large amounts of wasted energy and quality issues that result in non- compliant waste product and costly fines. This article covers our top 10 tips on how to get better efficiency in heat treatment processes while meeting industry standards, using modern technology designed with furnace applications in mind.

Introduction

Precise temperature control is critical for the heat treatment of automotive and aerospace parts that need to comply to standards such as Nadcap/AMS2750 and CQI-9. Poor control leads to components that have been overheated, under-heated or not soaked at the correct temperature for the specified length of time. Many difficulties can arise during heating, cooling, ramps and dwells including control of overshoot, rate of temperature change and stability. Add to this the necessity to prove the process was carried out to specification by securely recording and archiving the data, and you will find you really need to select the right equipment for the job.

These problems are easily solved using modern precision PID control and secure tamper resistant data recording techniques with smart reporting tools.

Our following top 10 tips show the benefits of precision control and secure data recording not only to help comply to standards but also to gain extra benefits in term of efficiency that also reduce costs.

Top Tips

1. Achieving the fastest ramp time without affecting quality

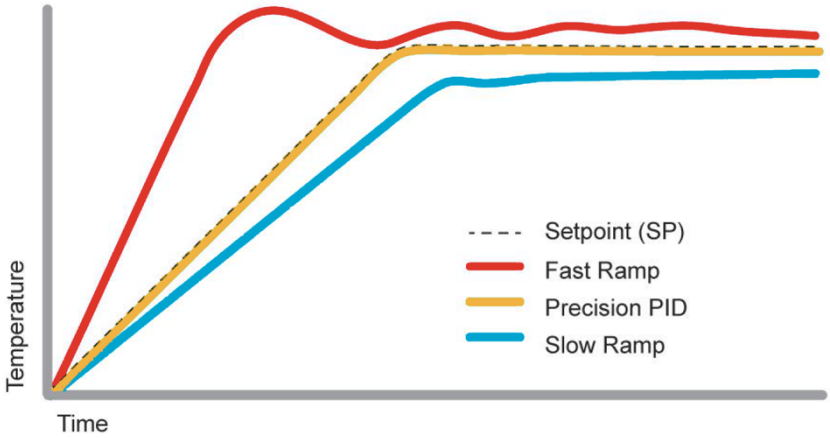
The faster a process can run, the more profitable it can ultimately be, but to maintain efficiency the speed must not affect the quality of the end product. Some materials and intricate workpieces have specifications that limit the rate at which they can be heated or cooled so as not to damage the material microstructure or distort the shape of the product. Ramping the temperature too fast can detrimentally affect the process resulting in quality variations and possible scrap material. The difficulty of achieving a uniform temperature across large furnace areas and workpieces during the ramp is due to thermal lag (also known as thermal gradient and Delta T) and in the case of material for aerospace and automotive applications it is often a requirement to prove that the rate of temperature change in the workpiece did not exceed specified limits during the ramp in order to meet regulatory standards. Multiple temperature measurements must be made across the workpiece s and the results fed into the temperature controller to help control a uniform temperature across each workpiece, and the data must be recorded for reporting and audits.

The secret to achieving ramps to the setpoint temperature as fast as possible without exceeding the limits of the material is to use a high accuracy precision controller with a ramp rate feature built into the functionality of the programmer. This kind of controller has high accuracy inputs and outputs that will maintain tighter control of the process variable (PV) keeping it closer to the setpoint (SP) than basic controller models. Often, this type of controller will also contain special algorithms that help prevent overshoot at the end of the ramp. For simple configuration of the ramp rate feature, look for set point programmers with data entry in a spreadsheet style format where the individual ramps can be set by Rate (the rate at which to ascend or descend to the setpoint per second, minute or hour) or Time (the time in which to achieve the setpoint).

Modern controllers with LCD, OLED or TFT display screens can show the plotted ramp rate SP against actual PV so you can visualize how your furnace or oven is adhering to set requirements, and if the temperature uniformity data is also being recorded to prove compliance to standards, the information can give an accurate overview of the temperature consistency in the ramp phase. Precision controllers and PLCs are now available with ramp rate features within the setpoint programmer along with secure recording features that not only help with compliance to standards but also provide enhanced process data for internal analysis and reporting on the overall efficiency of the furnace.

Ramp Rate

A ramp rate feature controls the rate of change to setpoint, keeping the material within its specified temperature limits and preventing damage and distortion in the workpiece



2. Reducing temperature overshoot for better efficiency

During the heating and cooling cycle of heat treatment processes, whenever the temperature overshoots or undershoots, energy is being wasted. When heating, once the furnace has reached its setpoint, the heaters will switch off, but due to residual heat in the walls and heaters themselves, the temperature of the furnace continues to rise causing it to (overshoot). Energy is wasted and the work piece could be damaged by overheating, needing intervention for quality assessment. Time is also wasted while the PV returns to SP, meaning overshoot results in a longer process time, wasted energy and wasted time for the quality engineer.

For processes where time and energy is being wasted in this way, the solution is to replace the temperature control with a Precision PID Temperature Controller or Precision PLC. Intelligent models have specific algorithms embedded in the control strategy that take care of common heating and cooling problems, keeping the PV as close to the setpoint as possible to prevent the unnecessary waste of energy while carrying out the process in the fastest conceivable time.

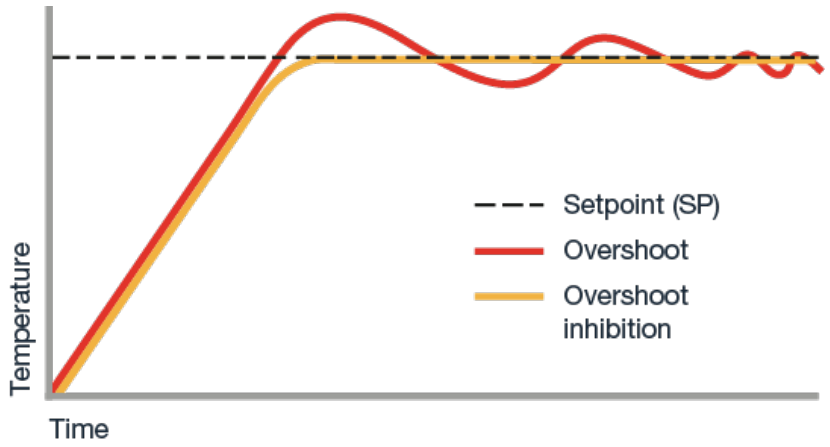
In heat treatment applications where it is important to comply to the relevant standards, useful control features to look for are algorithms that inhibit temperature overshoot during the start-up heating phase, reduce overshoot during ramps, and stabilize the PV during dwells. The easiest models to configure incorporate pre-made function blocks for features like PID (control) Cutback (overshoot inhibition) and Cascade (fast response to SP change to reduce temperature lag in the load) with typical default values set for easy configuration.

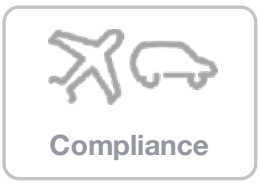
Basic controllers do not have the features to achieve the level of precision control that can save energy costs, reduce processing time and prevent the overheating of valuable materials. In most furnaces, the cost of moving to precision control is minimal compared to the savings made over the lifetime of the furnace.

Overshoot

When operating temperatures are outside the desired setpoint, the result is:

- *Wasted time and energy*
- *Under or over heated material*
- *Possible non-conformance to critical temperature limits leading to scrap product*





3. Compliance to critical temperature limits

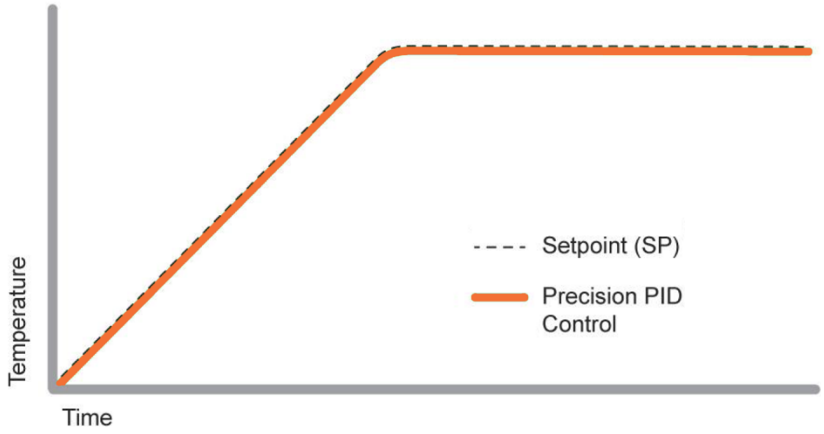
Processes in aerospace and automotive industries need to comply to strict standards such as NADCAP, AMS2750, CQI-9 and TS16949. Specifications covering topics such as monitoring and recording instrumentation, calibration and electronic records, sensors, and control must be adhered to, and failure to comply can lead to hefty fines lost business and loss of respect for the company involved. Field Test Instruments and Controlling, Monitoring or Recording instruments must meet the calibration accuracy demanded, typically with a readability of 1°F or 1°C and the material being treated must not be heated outside of its specified limits.

The benefits of Precision Control

By investing in precision PID control with accurate Inputs and Outputs, and better rejection to noise, you can be sure that the temperature you set is the temperature you get, and that you are meeting your limits while getting ROI by reducing your energy bills over the lifetime of the controller. Other useful features to look for are alarms and communication protocols that help to inform you when a critical limit has been reached. Modern control products with Ethernet communications are available with SMTP server functionality for sending emails when an alarm has triggered and have webservers built in so you can view what's going on from a PC, Tablet or Smartphone using a web browser.

Precision Control

Precision PID control contains special algorithms that help to keep the PV as close to SP as possible, even during ramps and other unexpected temperature variations



Thermocouple sensors used in high temperature environments degrade over time and heat treatment standards dictate the upper temperature limits and number of times a particular thermocouple sensor type should be used before replacement. Control and Automation products are available that can calculate the time, temperature and number of instances a thermocouple has risen above a certain threshold temperature, triggering alarms to indicate expired sensor periods.

The benefits of Secure Digital Data Recording

Process data needs to be securely recorded and stored for a length of time. While this is much simpler nowadays using a digital data recorder, recent innovations in precision PID controllers and PLC products include built in secure recording and color TFT displays with wash down fronts for use in dirty industrial environments

Recording by Batch

- *Quality signature digitally saved with the batch data*
- *Easy retrieval of data for reporting and audits*

Being able to record what happened during a batch process is very powerful, especially if something goes out of limits. A quality engineer will need to assess the data before signing off the Batch, a time consuming task, especially in older plants where paper procedures are still being used.

Full featured digital recorder products have batch functionality which enables the operator to record individual batches with a start and stop button on the screen, or by external input via a bar code scanner for example. The data from the batch is then easily retrievable by the quality engineer for assessment purposes via a PC. Software for reviewing the secure files can be used to zoom into areas where problems occurred and the historical data also shows all messages whether triggered by an alarm or entered manually by the operator. The reviewing software also allows digital signatures to be added to the batch for sign off. The main advantage of digital batch recording and signing is it saves time for the quality personnel and gives them all the data they need for easy reporting and compliance to standards.

Accredited Services

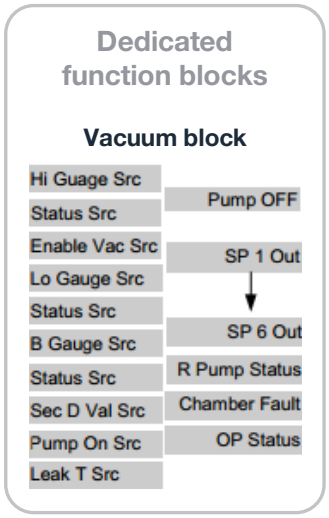
To help maintain accuracy, proficient companies also provide services such as Calibration, Temperature Uniformity Surveys (TUS) and System Accuracy Tests (SATs) at regular intervals, to ensure that temperature measurement products and systems are not drifting over time. The most efficient calibration services are those that are managed digitally. Modern companies offer online calibration services that give you a complete overview of the whole plant calibration status via a web browser and automatically inform you when calibration is due. Other features they provide are instant entry of calibration data in digital format, allowing calibration certificates to be created and uploaded immediately to the online calibration management tool, giving you the fastest easiest access for auditing purposes.

For companies that wish to carry out TUS themselves, some equipment manufactures supply field test instruments such as recording equipment specifically designed for the calibration of furnaces. Accurate to the demanding specifications of modern heat treatment standards like AMS2750 they include independently adjustable thermocouple input channels compliant to within +/-1°F or 0.6°C

4. What do we mean by Precision Control?

PID Control

Basic controllers are fine for many applications but when it comes to regulated industries, they are just not good enough. The difference between basic and precision controllers is in the embedded intelligent control strategies. Basic controllers may use a PID control algorithm which works well in normal applications that are predictable and do not need high levels of accuracy. The problems arise in applications where there is always some kind of variation in the load or process causing temperature lag in the system, or where sudden temperature changes can occur, such as when a furnace door is opened or a gas is introduced. Add to this the issue of having to comply to industry standards, and you will find what you really need is a precision controller.



Precision controllers use PID control but with additional algorithms unique to the company of manufacture that are specially designed to maintain control in certain situations and applications. For example the overshoot, lag and instability commonly seen in heat treatment applications can be better controlled using PID with Cutback and Cascade features. These work in harmony with each other to keep the PV as close to the setpoint as possible during the process.

It is worth searching out controller manufacturers who are knowledge experts in the heat treatment industry as they will offer products designed particularly for heat treatment applications, such as Zirconia Probe inputs, Vacuum Furnace Controllers, Carbon Potential Controllers and Thermocouple/Pyrometer Switchover Control. This type of manufacturer will also typically offer I/O, toolkits and function blocks specifically designed for better control of heat treatment processes that provide simple setup of control parameters for applications like Vacuum, Carbon Diffusion, 3-Gas IR, Zirconia Probe and AMS2750 standards.

Autotune

Setting PID terms and feature parameters on a basic controller is normally a time consuming manual task that requires a skilled operator or engineer. The benefit of modern precision controllers is the Autotune feature which sets a lot of the parameters automatically. This can be run by a less skilled operator, with very quick feedback that greatly speeds up the process.

Setpoint profiling

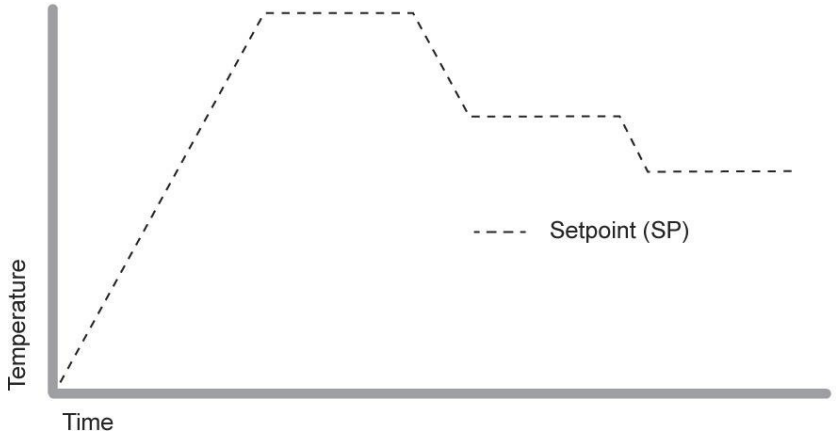
Heat treatment cycles often require multi stage control profiles to heat up, dwell and cool down the workpiece for specified amounts of time. These profiles are defined by the work piece material type, component specifications and regulatory standards, and are usually maintained against controlled recipes. Temperature profiling is a time consuming manual task when built in a standard control environment where typically, the entire program is built by creating function blocks by hand or in a list format, requiring many lines of instructions. The probability of making mistakes is high and it is difficult to make quick changes to the program.

The easiest way to program is by using a Setpoint Programmer (SPP) with easy segment parameter entry in spread sheet format that will closely integrate with the PID control to maintain the setpoint within a tight tolerance. Typically, SPP segments can be configured to Dwell, Ramp Rate, Ramp Time, Wait and Repeat in conjunction with other events, and the different programs can be easily selected using a recipe function.

Setpoint Programmer

A comprehensive but easy to use Setpoint Programmer works in harmony with precision PID control, improving the efficiency of heat treatment processes by:

- *Speeding up configuration time*
- *Reducing operator errors*
- *Preventing workpiece materials from overheating or underheating*



Gain Scheduling

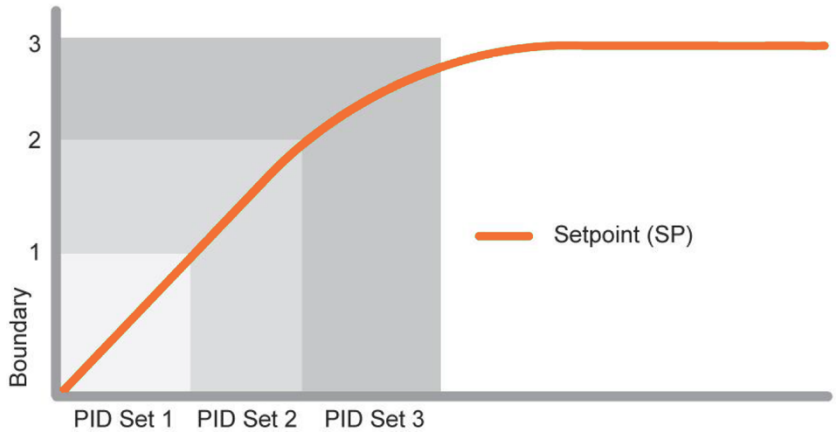
Today's furnaces tend to be used at multiple temperatures and their control performance can vary depending on the effects of convection, conduction and radiation at elevated temperatures. To ensure the tightest levels of control, precision PID controllers offer multiple ranges of PID sets (commonly called Gain Scheduling) that can be matched to the furnace characteristics at particular points in the program to help achieve those hard to reach temperatures.

Gain Scheduling

Extra gain can be implemented by the schedule each time a defined Boundary is reached

This could supply extra heat or cool gain to help achieve a difficult to reach set point

The parameters in the scheduled PID set can be autotuned, also known as Tune sets



Guaranteed Soak

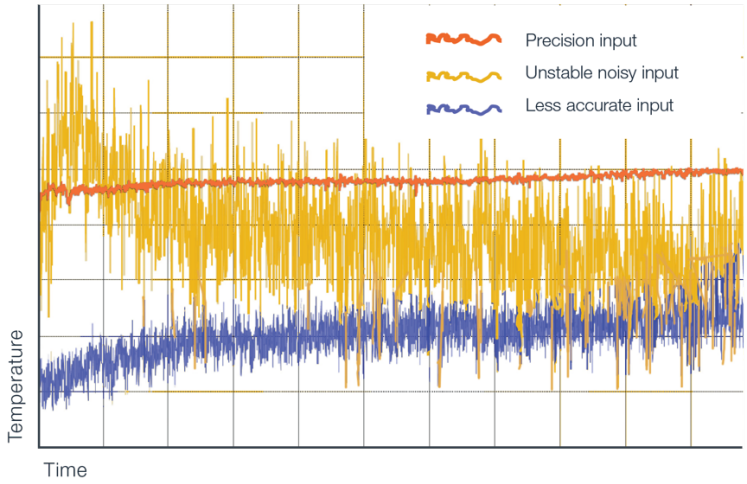
Specified soak times also vary and the best set point programmers can be configured to wait until every part of the workpiece has reached the specified soak time (known as Guaranteed Soak).

Accurate I/O

Accurate PID control cannot be achieved without accurate analogue Inputs and Outputs (I/O). The main issues that affect accuracy are electrical noise in the cables, interference from other channels and circuits, and temperature drift over time. In precision controllers, this is solved by the use of high quality components and good analogue circuit design. Look for I/O that is isolated from other channels and circuits, with specifications that quote the noise rejection and long term drift. A high noise rejection ratio and low ppm (parts per million) drift/year will help aid compliance with heat treatment standards by easily maintaining stability and accuracy within the specified calibration periods.

Accurate inputs

Accurate inputs with high rejection to noise help achieve precision PID control by supplying exact measurements to the PID algorithms for more precise calculations



Electric Utilities

Precise Power Control

The energy used in heat treatment furnaces is one of the biggest contributors to costs in the materials processing industry. Energy suppliers provide energy on a tariff and if not managed carefully it is possible to draw more energy at certain times than your tariff allows. This can result in hefty fines.

Many older style electric furnaces still use on/off control connected to electromechanical contactors in order to switch heaters on and off. The problem with this method is that it is nearly impossible to get good heater control as the heater is either 100% on or 100% off, no matter how much heat demand is actually required to get to the SP. The result is wasted energy, with the PV oscillating around the SP, and the uncontrolled way that heaters are switching on and off across a whole plant can cause you to exceed your agreed energy tariff. The switching of contactors also creates a lot of electrical noise on the mains supply that can affect other electronic devices and reduces the life of the heaters due to thermal stress.

The next step up is to use basic thyristors which have no moving parts and therefore are much more reliable. Models are available with different firing modes that gradually supply power to the heater based on % of demand. These methods provide smoother power control than on/off but can still create harmonic noise and flicker that reduce the power factor. Power factor is one of the main aspects that drives up energy costs. Most utility companies apply a surcharge when the power factor goes below 0.9 (or 90%). Over a year this can translate in thousands or even tens of thousands of dollars, depending on the size of the installation.

The best solution is to move to modern SCR (thyristor) power controllers. These smart devices are available with a large variety of industrial communications that allows them to communicate with each other across the plant. They provide multiple firing modes

for specific types of electric heaters and can automatically switch modes, for example from phase angle to bust firing based on resistance or temperature of the element. The key differentiators are specially designed algorithms for managing the power by evenly spreading loads across different furnace zones, multiple furnaces and the rest of the plant. This kind of Predictive Load Management uses clever load balancing, sharing and shedding strategies to equally distribute power and maintain a balanced overall consumption. Eliminating peaks in power demand helps make the best use of your energy and keeps finance managers happy by operating within your specified tariffs.

For more information on Predictive Load Management download Eurotherm white paper "Energy Cost Reduction through Load Balancing & Load Shedding"
http://www.eurotherm.co.uk/en-gb/products/power-control/epower/

5. Safety and over temperature alarms

During the heat treatment of valuable materials, it is sensible to use an over temperature alarm unit also known as a load policeman in order to trip heaters in the event of a serious control fault. If the heater gets stuck "on" for any reason, the workpiece will overheat, possibly resulting in the waste of a high cost product. For failsafe operation a separate controller or indicator is used and the alarm will typically be set a few degrees above the high limit to trip the alarm in the case of a failure. Different batches of product may have different critical temperature limits and a common problem is that the operator needs to change the setpoint of the load policeman manually for each type of material. This leaves a lot of room for error as the operator can forget to set the limit or incorrectly enter the data.

A simple way to solve this problem is to use a main controller that can retransmit its SP via 4- 20mA I/O or digital communications, to a policeman controller with a Remote Setpoint Input feature. The remote SP signal fed into the policeman can then be configured to trigger an alarm at a specified number of degrees above the SP, for example +10°C. Using this method prevents operator errors and is a reliable way to prevent any type of material from exceeding its critical temperature limit.

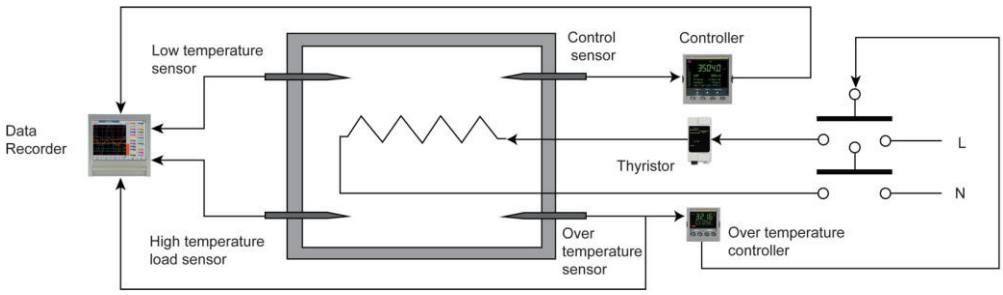
The same theory can be applied to heat treatment furnaces where personal safety can be compromised in the event of an excessive temperature and to meet safety standards such as NFPA 86. If the upper tolerance of the personal safety temperature limit is breached, not only can you alarm using the over-temperature policeman instrument but you can also use the device to automatically remove the power input to the Furnace, protecting personnel from harm and the plant from a hazardous fire situation. AMS2750 allows the over-temperature instrument to also serve as the high temperature reading and pick up the hot part of the Workzone based on the most recent furnace survey as long as this temperature is recorded for certain instrument types. A digital recorder can be used to record the temperature measurement from the policeman controller.

The benefit of using modern control and digital recording equipment is that alarms can be sent directly to the engineer by email or SMS, and the data from the event is digitally recorded for review afterwards.

Over temperature alarms

If the safety temperature limit is reached, the over temperature controller will cut off the power to the heater

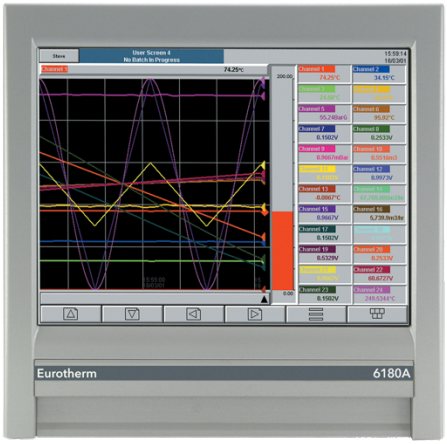
The same method can be used to protect a workpiece based on a hi-limit alarm applied to the load sensor



6. Moving from paper to digital recorders

For heat treaters who are still using paper recorders, there are ongoing problems involving cost and maintenance of replacing charts and pens, plus secure storage of the data in paper chart form. There is also the possibility of pens or paper running out during a batch. Missing data can result in wasted time for quality engineers while assessing the non-conforming process and can result in the possible scrapping of the product.

There are several benefits of moving to secure digital recorders. Firstly, there is a cost saving as you no longer need to buy, store and conscientiously dispose of paper and pen consumables. Secondly, you will save on maintenance time as there is no need to replace paper and pens on a regular basis and the product is more reliable due to less mechanical parts. Last but not least, the data is stored in digital format which is much more convenient to view on a PC, Tablet or Smartphone. Full featured secure digital recorders store data in a secure tamper resistant file format within the product which can be securely transferred to removable media (USB etc.) or servers over a network. The data can then easily be retrieved for quality checking, reporting and auditing, unlike paper charts which can easily be misfiled, lost, or run out during the process.



7. What do we mean by Secure Data?

By 2015, AMS2750 standards state that any electronic records created during calibration or the heat treatment process must be unalterable without detection, presentable in a both a human readable and electronic form for inspection, show evidence that the record was reviewed and provide methods to limit system access to those authorizing. The data must also be securely stored in an archive system but readily available for retrieval throughout the required retention period. Many data recording systems such as those within SCADA, PLCs and basic data loggers save data in .csv file format. This format, while very useful for easy import into spreadsheets, is in no way safe from tampering, or able to indicate that it has been tampered with, and therefore cannot be used for processes that require high level data integrity like 3rd party audits and government standards. Another problem can arise from the way data is collected. Some SCADA software packages record data not from within the recording product but over communication lines. If communication is lost, so is the data, making this kind of system unsuitable for regulated heat treatment applications.

When choosing a method of recording, the first feature to look for is a secure file format that is not editable. Data recorders and some precision PLCs are available that save data in binary check summed files which are resistant to tampering and only viewable using specific software. This is a much better solution than using .csv files which are easily editable and therefore not secure. An added benefit is that the files can be compressed so more data can be stored on the product itself before transferring to other media. Another important feature to look for is that the data is recorded at the point of measurement i.e. in the recording or control product, which solves the problem if communications are temporarily lost during transfer of data. Look for products with self-healing store-and-forward strategies that automatically backfill any missing data caused by breaks in communication as this will save time compared to transferring missing data manually.

Full featured recording products have security management options that provide a tamper resistant audit trail for recording User Names, Passwords and Access Permissions. All operator activity is logged and recorded in a secure database. For example, an operator could be given permission to change configuration by digital signature or they may need to get a second level of authorization from a quality engineer. The important point is that the changes will be logged for quality personnel and auditors to review should they need to. Features like these that bring traceability of ‘who did what’ in a process aid compliance to standards like NADCAP and AMS2750.

8. Recorded Data Saves Energy

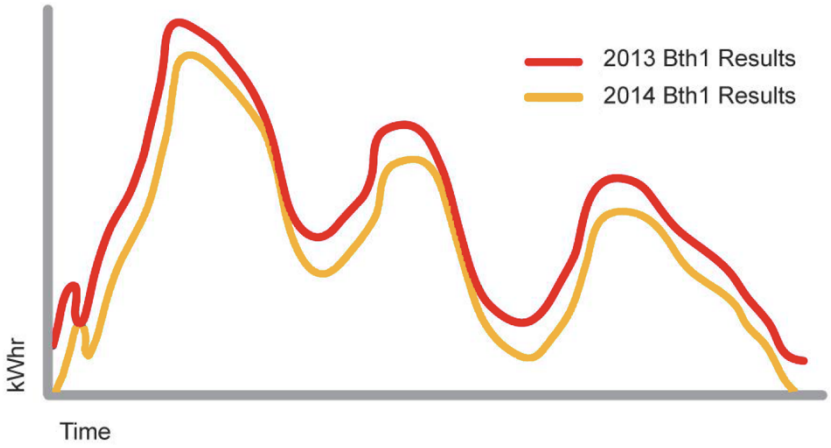
We often hear people say “I don’t know how much energy is being used by my process” and legislation is driving plants to review and report their energy usage. In older factories where production lines are still reliant on utility electricity meters it is often impossible to tell how much energy is used on individual lines and processes in the plant, and even if modern energy meters and sensors have been fitted at optimum points of measurement, you still need a way of collecting, recording and calculating the data in a meaningful way for analysis and reporting purposes.

Most modern energy meters have communications built in, allowing data to be sent to a logger or recorder for analysis and reporting. Data from probes and sensors can also be recorded by feeding the output signals into data loggers’ inputs. Full featured digital recorder models have advanced mathematical functions to carry out calculations on the data. The resulting signals can also be recorded, providing valuable information to engineers responsible for meeting energy saving targets and for reporting to management.

Energy Data

Comparing this year’s energy usage against last year’s in specific areas can prove that your implemented energy saving improvements are working

The recorded data can also be used for reporting in energy audits



Process & Machine Management

9. Benchmarking for Furnace Uptime

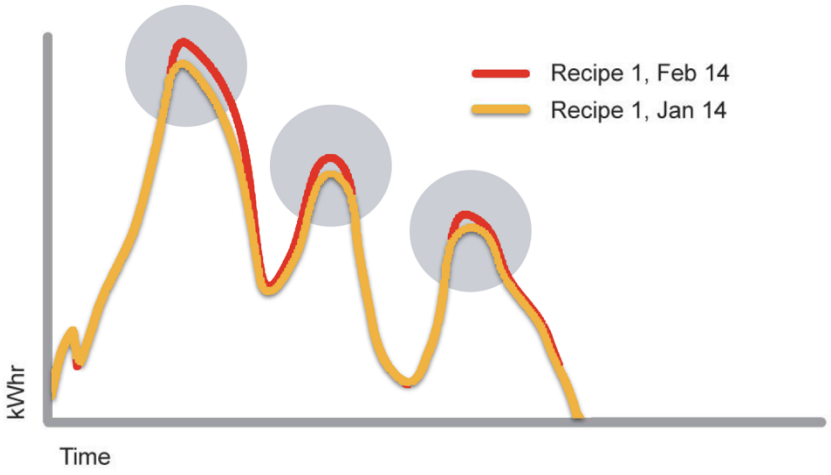
The equipment used in the treatment of materials can have a hard life, whether batch or continuous processes. Equipment like heaters, thermocouples, motors and compressors can become degraded over time and may not be operating at their full potential. It is difficult to know when components are wearing out and likely to cause problems in the process. Also, Overall Equipment Effectiveness (OEE) and Total Effective Equipment Performance (TEEP) are increasingly important Key Performance Indicators (KPIs) in modern business. OEE quantifies the performance of a piece of equipment or production line relative to its optimum capacity during its planned run time. The result is then measured against the maximum possible running time to calculate the TEEP. The calculations involve metrics based on loading, availability, performance and quality and the resulting information shows up efficiency problems like down-time due to unplanned maintenance and product quality issues.

The benefit of recording your process is that you can use the data to benchmark aspects of the output for comparison over time. For example, the energy used in a batch can be recorded and compared at monthly intervals. If more energy is being used, something could be going wrong in the process which can then be investigated early before a complete failure occurs. Also, given the benefit of visual data, maintenance personnel are often able to recognize when components are starting to fail. For example, a failing compressor will show a recognizable wave signal. The recording product can be configured to trigger an alarm based on aspects of this kind of signal pattern using maths functionality, informing the maintenance team and preventing unplanned down time. The ability to make comparisons between recorded benchmarked process data and current process data is becoming a valuable advantage to efficiency during manufacturing, improving profitability through better OEE and TEEP.

Benchmarking

When more energy is used to make the same product over time it can mean a component in the process is starting to fail

The time it occurs in the process can be a clue to which component or piece of equipment is becoming worn



10. Smart Reporting

We all need to supply reports nowadays, to prove compliance to process parameters, account for energy usage and present our KPIs. It is still common to see personnel manually creating report documents and often that input data needs to come from various sources. This can mean scanning or photocopying data and images like paper charts into digital format, manually manipulating and calculating data, and cutting and pasting information into documents by hand. For some people it can waste several days per month. There is a better way to produce these reports!

Most reports are required on a regular basis and the solution here is a software reporting package designed for industrial automation applications. These contain configurable report templates along with drivers for pulling data from a variety of common devices and file sources. The real time saver is that the data can be pulled in automatically over a network, creating your report the way you want it, saving it as a secure PDF and sending it to the right person. Collecting your data digitally at the source, enables you to save time in the everyday reporting process even if creating them by hand, but the most efficient way of reporting the data in the long term is to take advantage of a dedicated software reporting package, so you can get on with your daily tasks without the bother of time consuming manual reporting.

About Us

About Eurotherm

Eurotherm have designed 50 years of knowledge into our control and recording products which gives us the leading edge in precision control and secure digital recording. We have designed unique control algorithms, enhanced features and specialized heat treatment function blocks to simplify the control of heat treatment processes, enabling you to save energy, predict maintenance and protect the quality of your valuable assets.

Our intelligent recording method, unique secure file format and secure data transfer strategies for archiving, aid compliance to standards like AMS2750, NADCAP and CQI-9. From discrete products to full automation solutions and industrial reporting packages, we can help you save costs and improve your efficiency.

Get the most from your heat treatment process.

To find out more visit:

eurotherm.com/heat-treatment

About the author

Amber Watkin has over 25 years' experience in the Eurotherm portfolio across the Glass, Heat Treatment, Semiconductor, Life Science, and Food and Beverage industries. Over this time, promoting Eurotherm energy saving, efficiency enhancing solutions and services, designed for energy intensive, high performance, specialized and regulated thermal processing applications.

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