



The HERRING GROUP, Inc.

Professional Support Services

Vacuum Process Instrumentation and Controls

by

Daniel H. Herring

“The Heat Treat Doctor”[®]

© 2010/2011 The HERRING GROUP, Inc.

This is the seventeenth in a series of articles about Vacuum Heat Treatment and looks at the subject of instrumentation and controls. This subject is complex, and one in a constant state of flux, changing as technology advances are made. As such, we have surveyed the current State-of-the-Industry and report our findings here.

Instrumentation and process controls used on vacuum furnaces in the heat treatment industry are extremely diverse due in large part to the fact that the life of a vacuum furnace can range from 20 to 50 years! The intent here is to report the results of a survey of major equipment manufacturers to better understand their product offerings today and to look at the current and future State-of-the-Art with respect to instrumentation and controls.

Introduction

“Adaptive” process control systems are utilized on today’s advanced vacuum furnaces. Depending on the machine or process, different variables exist that must be monitored, controlled and/or changed during the cycle to achieve maximum throughput, repeatable processes and stringent quality results. Sensors monitor a selected process or equipment parameter; send the gathered data back to a controller, which then compares it to a predetermined value or set point. Through calculations, a controller sends a signal back to the device to make the proper adjustments to obtain a “controlled” process.

An everyday example would be cruise control on an automobile where the speed set point must be maintained. The variables of speed, acceleration, and resistance are monitored, and then adjustments are made to reach the desired end results. Control systems on vacuum furnaces function similarly by, for example, optimizing and regulating temperature and pressure to achieve the required process conditions and produce repeatable results. Programmable Logic Controllers (PLC’s), sensors, and computers make this all possible. In turn, data trending, real time process monitoring, and data

Page 1 of 51

The HERRING GROUP, Inc.
Home of “The Heat Treat Doctor”
P.O. Box 884

Elmhurst, Illinois 60126-0884

Tel: 630.834.3017 / Fax: 630.834.3117 / Cell: 630.640.9048

E-mail: dherring@heat-treat-doctor.com / dherring@ameritech.net
www.heat-treat-doctor.com



The HERRING GROUP, Inc.

Professional Support Services

collection for permanent retention is commonplace. By analyzing this data, new cycles, containing modified variables, can give better results in less time.

There are a number of manufacturers of hardware/software that make this “adaptive” technology possible. Allen-Bradley, Siemens, Honeywell, and Eurotherm are a few of the recognized leaders in industrial controls, especially in the vacuum furnace industry.

The Survey says...

Here's a look at what the various vacuum furnace manufacturers had to say.

Surface Combustion, Inc. looks at ...

1. *Simple process control systems*
2. *Temperature ramping requirements*
3. *Who makes what?*
4. *Programmable Logic Controllers (PLC's) for cycle framework and single chamber vacuum furnaces*
5. *Hybrid control systems*
6. *Utility monitoring and interlocks*
7. *Interlocks for vacuum pumps, heating systems, and gas quenching.*
8. *Control needs for a diffusion pump*
9. *Partial pressure control and vacuum sensors*
10. *Multi-chamber vacuum furnaces and control of motions*
11. *Vacuum carburizing controls*
12. *Supervisory computer systems*

Simple Process Control Systems

Vacuum furnace process control systems (Fig. 1) are somewhat similar to atmosphere style batch furnace control systems; however tend to be somewhat more sophisticated, especially from a temperature control standpoint.



The HERRING GROUP, Inc.

Professional Support Services

Figure 1
(Courtesy of Surface Combustion, Inc.)



Typical Vacuum Furnace Control Cabinet Showing Ramp Soak Programmer, High Limit Instrument, Multi-point Strip Chart Recorder, Vacuum Instrument, Alarm – Status indicator Lamps, Selector Buttons, and Audible Alert Horns.

Temperature Ramping Requirements



The HERRING GROUP, Inc.

Professional Support Services

Naturally temperature control is the first requirement. Whereas most atmosphere furnaces tend to change set points only a couple times per cycle and usually heat as fast as possible, vacuum furnace cycles usually incorporate a heating ramp and quite often a reverse or backward ramp. Ramp rates are usually displayed in “degrees per hour” or “degrees per minute”. A traditional single loop PID (Proportional Integral Derivative) controller would not typically be used for temperature control alone.

Based on this need for more complicated temperature cycles, a control system with setpoint ramping, as well as multiple setpoints is a must. It is not uncommon for vacuum furnace recipes to have 10 or more segments in a given recipe.

The temperature controller would have as a minimum, a PID (Proportional Integral Derivative) control function (as opposed to simple on off control), coupled with a ramp/soak programmer. Some controllers will also have “auto tune” capability, along with anti-overshoot algorithms, often-dubbed “fuzzy logic”.

Who Makes What

The world of process control and programmable controller suppliers is vast, as is any electronic offering in today’s digital world. The process controllers listed have been referenced due to their popularity within the general heat treat industry and only a brief summary of their features given. If one were to be investigating the purchase of one of these control systems, there is a great number of other worthy suppliers with comparable or even more sophisticated systems.

A typical entry-level controller commonly used for temperature control would be a Honeywell DCP 550 ramp soak programmer (Fig. 2). Similar products from other suppliers are also available and are comparable. Based on user preferences, one could also consider a Eurotherm model 2704, a Yokagawa model 8838, or SSI 9220 depending on features or experience with the product line.



The HERRING GROUP, Inc.

Professional Support Services

Figure 2
Honeywell DCP 550



We will also delve into the use of programmable logic controllers (PLC's) which are used for logic control and interlocks, and can be expanded to also include the functions of the discrete "ramp soak programmers". A PLC typically will offer the ultimate in designer flexibility. The Eurotherm 2704 Ramp soak programmer with recipes and expandable digital I/O (Fig. 3) is one such device. This unit has up to 60 recipes or 600 total segments. This unit also has 8 analog inputs and 8 analog outputs and up to 43 digital I/O.



The HERRING GROUP, Inc.

Professional Support Services

Figure 3
Eurotherm 2704



Another typical PLC is the Yokagawa UP55 Ramp Soak Setpoint Programmer (Fig. 4) with 30 recipes, each having 99 steps. This unit has 9 digital inputs and 18 event outputs; 8 PV events, 16 time events and 8 alarms.



The HERRING GROUP, Inc.

Professional Support Services

Figure 4
Yokogawa UP55



Programmable Logic Controllers (PLC's) for Cycle Framework & Single Chamber Vacuum Furnaces

To work in conjunction with the Ramp Soak programmer, it is common to use a small programmable controller. An entry-level unit for the PLC would be an Allen Bradley MicroLogix PLC (Fig. 5). This unit, or equal, simplifies the control of the many event situations as well as cycle interlocks.



The HERRING GROUP, Inc.

Professional Support Services

Figure 5
Allen Bradley MicroLogix PLC



In a single chamber furnace, the furnace heating chamber starts cold or at room temperature. From that point, a load is placed in the heating chamber and the furnace door is closed. Once the door is closed, a clamping or locking ring is often used to retain the door safely closed should the furnace be equipped with high pressure gas quenching. The PLC will test that the door is fully closed and activate the evacuation valve to allow the vacuum pumping system to evacuate the heating chamber of air and other contaminants.

The logic of the PLC will also include alarming if the required utilities are not turned on. Hardware relays are used for safety interlock purposes, but PLC's lend themselves to displaying that an interlock condition is present.

Vacuum furnaces usually have a two-stage vacuum pump and often a diffusion pump for achieving higher vacuum levels. Control of the "mechanical vacuum pump", or what is often called the "roughing" pump has the minimum requirements of a selector switch; motor starter with overloads, and fuses. The "vacuum blower" or booster which compresses gas or atmosphere going to the mechanical pump, has the above components



The HERRING GROUP, Inc.

Professional Support Services

and usually has a pressure switch to prevent the vacuum blower from turning on until the appropriate vacuum threshold is obtained. A typical threshold might be 30 torr. The pressure switch can be electronic such as a Pirani gauge, or might be a simple mechanical switch. Turning on the vacuum blower too early will overload the drive motor and causes overloads to trip or fuses to blow.

Additional interlocks exist which do not allow the heating system to be enabled until the furnace has pumped down to a low vacuum setting, usually on the order of 0.05 torr (50 microns). Should the furnace be equipped with a diffusion pump, the heating system and temperature control is further held off until the furnace reaches sub micron levels, 5×10^{-6} torr for example. These values are usually programmed into the vacuum-measuring instrument on simpler control schemes, or could be part of a recipe on more exotic control system systems.

Hybrid Process Control Systems

An alternate process control system often used is a “*hybrid process control system*”. The hybrid controller is a combination PID process controller with many PID loops available through software and integral ramp soak programmer. Instead of a dedicated loop controller with ramping capability, the system is programmable to have one or more PID loops available with any of them coupled to RAMP/SOAK programmer modules. The Honeywell HC-900 Hybrid Controller (Fig. 6) and close up of Color Operator Interface (Fig. 7) is one such example.



The HERRING GROUP, Inc.

Professional Support Services

Figure 6
Honeywell HC-900

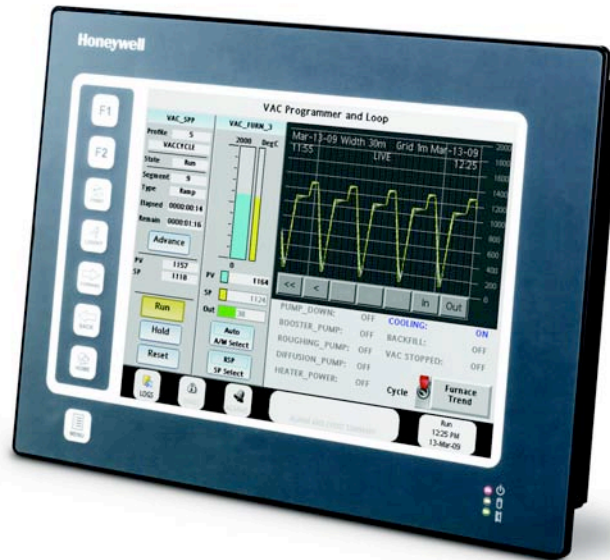


Figure 7
Honeywell HC-900 System





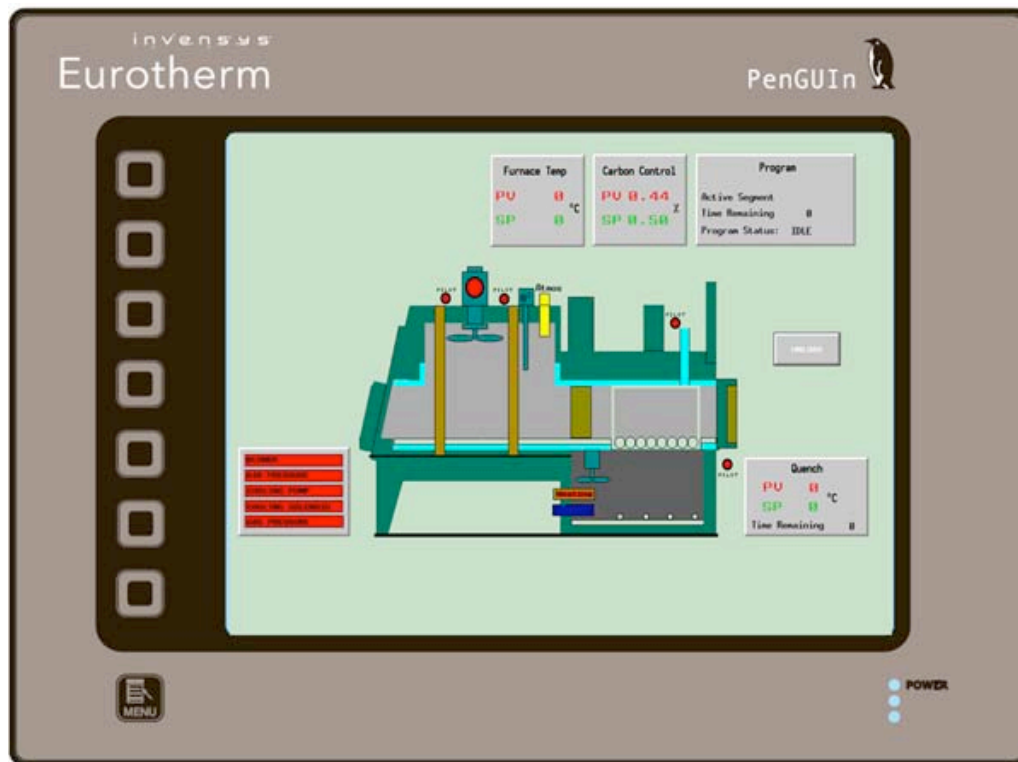
The HERRING GROUP, Inc.

Professional Support Services

Note: The personal computer is not required after the system has been programmed, unless computer trending of the process data is desired.

The hybrid controller also has PLC logic capability, so this type of controller replaces the ramp/soak programmer and also the conventional PLC. Most systems have a color Human Machine Interface (HMI) to allow the operator to take control of the entire furnace operation (Fig. 8). Most PLC's are programmed in ladder style logic, however hybrid controllers are generally programmed through the use of function blocks.

Figure 8
Penguin Panel HMI for Eurotherm Hybrid System
(Photo Courtesy of Invensys Eurotherm)





The HERRING GROUP, Inc.

Professional Support Services

The advantages of the hybrid controller are the logic and process control is performed in the same box. This approach saves money on inputs and outputs that otherwise are required to pass information from the PLC to the ramp/soak programmer and vice versa.

The hybrid controller typically has preformatted displays. The preformatted displays have the advantage that different furnaces have the same look and feel for a furnace operator. This also allows the design engineer to quickly configure the unit for the operator. The drawback to this approach, is the dedicated layout does not always allow for custom displays. This limitation can be avoided by using higher end HMI's from the supplier or third party HMI's which typically provide a blank sheet of paper approach and displays can be laid out to meet any configuration desired.

Third party HMI's using Wonderware development software (Fig. 9) are ideal when "canned" or programmed screens will not work well for an application.

Figure 9
Wonderware Software Package
(Photo Courtesy of Invensys Eurotherm)





The HERRING GROUP, Inc.

Professional Support Services

Utility Monitoring and Interlocks

Due to the very high operating temperatures possible with vacuum equipment, extreme care must be given to assuring utilities are available at all times, and in the event of loss of utilities, that the furnace is automatically put into a safe condition.

Checks and precautions center around verifying, for example, water pressure and water flow to all water-cooled components. Without water flow to the heating system transformer, the casing, power feed through, diffusion pump, and other water cooled members, severe damage could occur to the furnace as well as unsafe operating conditions. The alarm circuits are usually provided by hardwired relays, alarm contacts, and interlocks.

Display on an HMI is often provided to alert operators as to the problem, but alarm action and intervention is always hardwired. Alarm circuits are usually provided by a separate source of electrical power as standard practice. Gas supplies for quenching, usually nitrogen or argon are also tested by the use of pressure switches, and must be “ON” before a typical vacuum furnace cycle can start. Recommended practice is also for a furnace operator to visually verify the above situations are met as a further precaution. Under loss of power, the evacuation valve is always closed to prevent air from back streaming through the vacuum pumps and into the furnace. Many customers maintain water flow with a natural gas or gasoline powered backup water pump. Some systems go to “city water” during power failures also.

Once the safety requirements are satisfied, which include all utilities being present, water is flowing to all water cooled components, no alarms are active, and the furnace has been evacuated to the preset levels, the heating system is then allowed to turn on. On multi-chamber furnaces, similar precautions and interlocks are required, however the heating chamber, once heated, will stay hot and evacuated.

Control Needs For A Diffusion Pump

Some vacuum furnaces are equipped with one or more diffusion pumps (Fig. 10) to allow the vacuum levels to be further reduced by a factor of 1000 or more. While a typical vacuum furnace can operate at 0.05 torr (50 microns) while heating, diffusion pumps can further reduce vacuum pressure to 1×10^{-6} torr (0.001 micron) or even lower with larger pumps.



The HERRING GROUP, Inc.

Professional Support Services

Figure 10
Typical Diffusion Pump



Diffusion pumps have no real moving parts, however they have an electric heater, much like the heater on a home electric range that heats the diffusion pump oil to approximately 175°C (350°F) or higher. The electric heaters typically free run and have a mechanical high temperature switch to turn off the heaters should water flow be inadequate. The diffusion pump has a large inlet valve, often called a right angle valve, which is the same diameter as the diffusion pump. A downstream valve, called the fore line valve, is provided for connection of the outlet of the diffusion pump to the mechanical vacuum pump and vacuum blower. Control of the right angle valve and the fore line valve are controlled by the PLC when the diffusion pump is to be activated. Prior to being able to use the diffusion pump, the diffusion pump heaters must be on for at least 30 - 60 minutes to allow the pump oil to become vaporized. A vacuum sensor is also used downstream of the diffusion to assure the gases from the diffusion pump are being sufficiently taken away. Should the downstream sensor exceed a preset level, the right angle valve will immediately close until the micron level returns to a safe level.



The HERRING GROUP, Inc.

Professional Support Services

The PLC is used to enable the heaters, both valves, and most importantly “valve timing” which is critical to prevent any form of back streaming from occurring. The diffusion pump also requires a small holding pump, which is another vacuum pump downstream of the diffusion pump. The holding pump typically is not controlled by the PLC, and is simply connected to a motor starter, overload, and fuses.

Partial Pressure Control and Vacuum Sensors

Most of the time, a vacuum furnace will operate attempting to remove all air (atmosphere) and contaminants from a hot zone and the pumps are running full out. There are times however when too hard of a vacuum can vaporize materials being processed. A typical application is high speed M series steel, which is routinely processed at 1175°C (2150°F) or higher. This series of steel has chromium, among other alloys, that if exposed to high vacuum levels would deplete the chromium content through vaporization.

To alleviate this condition, “partial pressure” control is activated where argon or nitrogen gas is bled into the furnace while the vacuum pump is trying to take it away. A typical partial pressure setting for M series steel would be 0.75 torr (750 microns). The partial pressure circuit is usually activated above a threshold temperature, 1010°C (1850°F) for example. At temperatures below 1010°C (1850°F), the vacuum system runs at full out and vacuum levels could be easily under 0.05 torr (50 microns). Above 1010°C (1850°F), the partial pressure circuit is activated (usually by the PLC from a Recipe request) and a solenoid valve allows nitrogen or argon gas to flow into the vessel. Once the partial pressure setpoint is reached, 0.75 torr (750 microns) in this example, the solenoid is closed. A dead band prevents the solenoid from cycling too quickly.

Another variation of partial pressure control allows a high flow sweep gas to pass through the furnace. In this situation, furnace pressure may be much higher, easily in the 2 - 10 torr range. This higher pressure is usually just a result of the higher gas flow going into the furnace. This high flow of gas is designed to move contaminants in the furnace quickly away through washing or sweeping. The vacuum pump typically runs full out in this situation, and the inlet gas flow rate is controlled via a fixed orifice or mass flow controller.



The HERRING GROUP, Inc.

Professional Support Services

Vacuum furnaces require at least one vacuum sensor, and some furnaces can easily have three or four. Vacuum sensors are made by a number of suppliers, including MKS, Varian, Televac, and Leybold Heraeus to name a few.

Generally, the vacuum furnace uses a small sensor to measure the actual vacuum level, and a vacuum instrument digitally displays the vacuum level and also generates a recorder or controller output voltage. The vacuum instrument also provides switch contacts or trips. Traditional output voltage ranges are 0-10 VDC or 4 – 20 ma. “Trip contacts” are important and are used as thresholds to turn on the heating systems, activate valves, or turn on the vacuum booster.

The common sensors used to measure vacuum levels down to 1×10^{-3} torr (1 micron) are:

- Thermocouple gauge tube
- Pirani vacuum sensor
- Capacitance manometer

Thermocouple gauge tubes work on the principle of thermal conductivity using a heater and thermocouple. The lower the vacuum level, the less heat that is transferred from the heater to the thermocouple. Vacuum readings are detected from the thermocouple voltage.

Pirani sensors are the most common and are modestly priced. They must be standardized to gas present in the furnace. Therefore, if they are measuring air or nitrogen, they read normally. If the atmosphere is argon or hydrogen, they must be standardized to those gasses.

Capacitance manometers do not need an instrument and are not sensitive to the gases in the furnace. They cost more than a Pirani sensor or thermocouple gauge tube, however can be exposed to any type of gas including vacuum carburizing gases and will read accurately. The above sensors are typically used down to vacuum levels of 1 micron.

Cold cathode sensors are used to measure high vacuum levels when diffusion pumps are in use. They measure down to sub micron levels and have a logarithmic output generally. Cold cathode sensors can be easily attacked by furnace contaminants, so it is important to have a spare sensor available.



The HERRING GROUP, Inc.

Professional Support Services

As part of vacuum sensor calibration, it is recommended a mercury manometer designed for vacuum service be used to test. Also calibrate the vacuum sensor on a periodic basis. Knowing accurately the vacuum level is as important as accurately knowing the furnace's temperature.

Multi-Chamber Vacuum Furnaces and Control of Motions

In addition to single chamber vacuum furnaces, there are also multi-chamber vacuum furnaces (Fig. 11) that have dedicated chambers for heating and quenching. Quenching can be under vacuum in an oil quench tank, or under inert gas in a gas pressure quench. Since there are multiple chambers for heating and quenching or cooling the workload, the furnace must also have material handling apparatus to transfer the load from one chamber to another.

Figure 11
Two Chamber Gas Quench Multi-Chamber Vacuum Furnace
(Courtesy of Surface Combustion)



Multi-chamber vacuum furnaces are generally controlled by a PLC, however some may be controlled by a hybrid control system. This furnace has an Allen Bradley PLC. The



The HERRING GROUP, Inc.

Professional Support Services

PLC controls all valves, all motions, temperature control, partial pressure control, and everything except safety circuits, which are hard-wired.

The control of a multi-chamber furnace is substantially more complicated than that of a single chamber furnace. In traditional two chamber or three chamber vacuum furnaces, control of chamber pressure must be done in tandem with the actual motion control. Therefore, before a door can be opened, pressure between the two chambers must be equalized by either venting a chamber under vacuum up to atmospheric pressure, or by evacuating a chamber to a hard vacuum should the door be opening to another chamber under hard vacuum.

Typically a PLC will be used for the control of motion, as well as control of evacuation valves, backfill valves, and vent valves. A typical vacuum furnace HMI using Allen Bradley PanelView Plus (Fig. 12) has screens to allow furnace operators to easily access controller settings, real time process variables and know where the load(s) are at any given time. The furnace shown has a primary PLC for control of the system with remote I/O to individual chambers.

Figure 12
HMI Interface

CONFIGURATION FURNACE VACUUM - ACTIVE ALARM(S)	
PUMP OFF DELAY (SECONDS):	10
BLOWER ON (TORR):	30.000
BLOWER DEADBAND (TORR):	2.000
VALVE OPEN DELAY (SECONDS):	10
HEATING ON (TORR):	0.050
HEATING DEADBAND (TORR):	0.900
PUMP DOWN LEVEL (TORR):	0.020
PUMP DOWN ALARM (MINUTES):	30
LEAK RATE TEST	
TEST INTERVAL (CYCLES):	5
DURATION (MINUTES):	30
STABILIZE DELAY (SECONDS):	30
ALARM RATE (MICRON/HOUR):	50.000
RECIPE GUARANTEES	
HIGH (TORR):	0.050
LOW (TORR):	-0.050
DIFFUSION PUMP: YES	
HEATERS ON (TORR):	0.100
HEATERS DEADBAND (TORR):	0.350
WARMUP (MINUTES):	30
HEAT ENABLE (TORR):	5.0 x 10 ⁻⁴
HIGH VAC ON (TORR):	0.050
HIGH VAC DEADBAND (TORR):	0.200
SELECTOR SWITCHES	
PREVIOUS <<<	NEXT >>>
MAIN MENU	SUB MENU
SILENCE ALARM(S)	
ALARMS	



The HERRING GROUP, Inc.

Professional Support Services

Figure 13
Multi-Chamber Vacuum Carburizing System with Four (4) Heating Chambers,
One (1) Oil Quench Chamber, & One (1) High Pressure Gas Quench
(Courtesy MMS Thermal, Davenport, IA)



Vacuum Carburizing Controls

Carburizing in a vacuum furnace has become a popular process. Vacuum carburizing furnaces require the most sophisticated control systems. In addition to a “recipe” for temperature, these systems require pressure control loops to operate the furnaces in the 2 – 10 torr range if they are low-pressure vacuum carburizing systems. The pressure control loops place a restricting valve between the vacuum pump and the carburizing chamber. As the valve closes, pressure in the chamber raises, and likewise will move toward lower torr levels as it opens. The control valve, along with a PID pressure controller, maintain vessel pressure at a given torr setpoint while the carburizing gases are flowing.



The HERRING GROUP, Inc.

Professional Support Services

Vacuum carburizing operates in a series of carburizing “boosts” followed by a related “diffuse” segment. These times can be as short as a few minutes to as long as hours. The control system recipe must be capable of a high number of segments for these boost and diffuse segments. Cooling to a pre-quench temperature, as in atmosphere carburizing is also common. Computer programs (Fig. 14) are used to determine the actual boost and diffuse times based on desired case depth, carburizing temperature, base carbon and diffusion slowing elements such as nickel, and the material’s carbide forming elements such as chromium, molybdenum, or vanadium.

Figure 14
Process Recipe Screen

Boost1	Boost2	Boost3	Boost4	Boost5	Boost6	
0.409	0.106	0.078	0.063	0.052	NA	Hrs

Diffuse1	Diffuse2	Diffuse3	Diffuse4	Diffuse5	Diffuse6	
0.991	1.294	1.322	1.337	1.348	NA	Hrs

Decay 1 =	0.8	Decay 4 =	0.8
Decay 2 =	0.8	Decay 5 =	0.8
Decay 3 =	0.8	Decay 6 =	NA

Vacuum carburizing recipes also require setpoints for carburizing gas flows. These setpoints, typically are channeled to mass flow controllers for traditional gases such as methane, propane, acetylene and often include hydrogen. The “units of measure” are



The HERRING GROUP, Inc.

Professional Support Services

often “liters per minute” for these gases. For liquid vacuum carburizing media, such as cyclohexane, an injector pulse width in milliseconds is also provided as a setpoint.

Supervisory Computer Systems

Often a customer desires further control either for the furnace operator, or for enhanced documentation involving critical processes. This desire can be accomplished by adding either a personal computer, or an industrial PC that would reside by the furnace.

There are many directions one can pursue and the actual selection should be based on what features are needed to be fulfilled, along with other issues like compatibility with other furnaces or other production equipment. Some companies offer “canned programs” where the end user or the OEM simply fills in the blanks and the programming is complete. Other companies offer programs that require a great deal of configuration and can easily require several months of programming. The latter approach provides the end user with a product that fits seamlessly into their operation. The “canned” program is quick to implement and usually simple to operate. Should the end user need a feature that is not provided with the program, the end user may be “stuck” at that point in time.

The first requirement of the supervisory system is to make sure the furnace controllers are capable of communicating with the supervisory system. The equipment described in this article has models that are available with computer communication capability. This today is usually Ethernet or Modbus, however other protocols exist and will work.

What should the supervisory system (Fig. 15) do? There are many functions that a supervisory system can perform. The following is a partial list of items to consider:

- Recipe cycle upload and download, which simplifies entering recipes especially if more than one furnace exists.
- Controller configuration settings download, which allows rapid set up a controller is replaced.
- Operation using part numbers and assurance the recipe run agrees with the part number.
- Load scheduling, helps manage which furnace should process a given load or batch of parts.
- Loading instructions, photos, fixture requirements, part orientation, etc.
- Bar code operation to eliminate mistyped recipe or part numbers.

Page 21 of 51

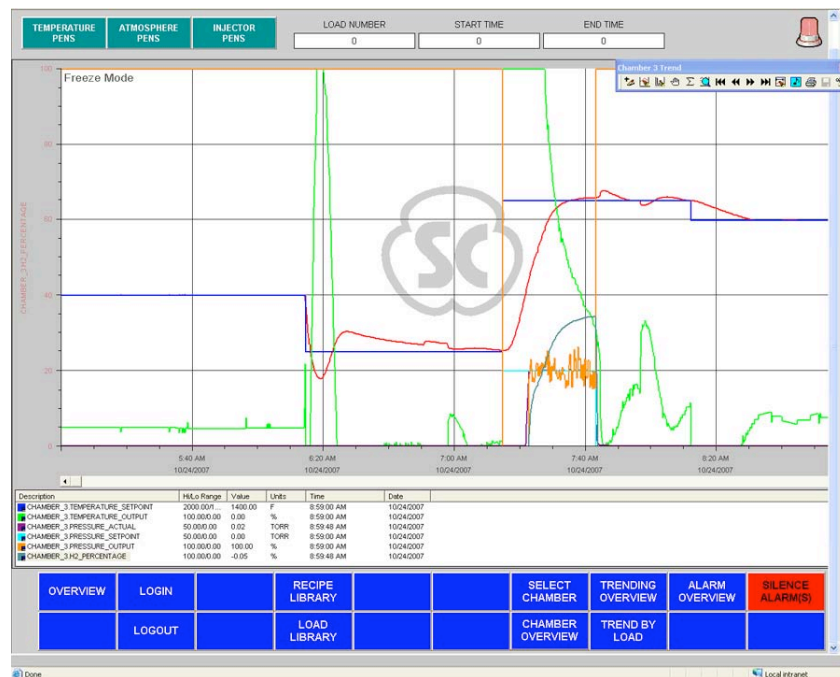


The HERRING GROUP, Inc.

Professional Support Services

- Alarm tracking, which documents to the hard drive, furnace alarm issues that may occur and when they are corrected.
- Maintenance and routine calibration reminders, as well as documenting when they are performed.
- Equipment checks such as temperature surveys or leak up rates.
- Process variable trending, along with setpoints and controller outputs. Can also include load thermocouples, vacuum level, mass flow controller levels, backfill pressure, etc.
- Real time remote viewing of the equipment in the office or remote site. This feature often helps in equipment troubleshooting and allows experts at a remote location to analyze equipment or process troubles.
- Lab testing requirements and integration with lab metallurgical finding.
- On-line operating instructions, which can also include startup or shutdown procedures.
- Integration into an enterprise system.

Figure 15
Computerized Data Storage for a Vacuum Carburizing Furnace





The HERRING GROUP, Inc.

Professional Support Services

Vac-Aero International talks about... the Challenges of Vacuum Processing

Temperature control in a vacuum heat treating environment can be difficult because of the changing heat transfer characteristics of the furnace as it moves from convection to radiation and conduction. The rapid heating rate of a vacuum furnace demands precise control, including setpoint program control with soak guarantee inputs.

Vacuum furnaces (Fig. 16) are often used for a variety of products and processes by the heat treater making recipe management an important function. Overshoot of temperature set points is usually not tolerated for metal treating applications. Setpoint program control is often applied to the temperature, vacuum level and gas pressure with extensive interaction between these programs and also with the logic control.

Figure 16
Modern Vacuum Furnace Controls



Page 23 of 51



The HERRING GROUP, Inc.

Professional Support Services

Vacuum furnaces are used in the metal treating industry for applications such as hardening, case hardening, brazing, melting, thin film deposition and the like. They are used to bring materials to high temperature with a minimum of surface interaction reaction (e.g. oxidation). In addition, surface and internal contaminants on the metal surface are volatilized and removed.

Vacuum furnaces for heat treating and brazing are typically single chamber furnaces operating batch cycles. The batch cycles vary between processes but commonly require regulation of temperature, vacuum and sequence logic. The temperature and vacuum interact extensively with the logic.

A typical heat-treating cycle starts after the product is loaded into the furnace and the door is clamped shut. Some users secure the furnace and perform a leak test before proceeding. A roughing vacuum pump lowers the pressure to about 0.05 torr (50 microns). An optional diffusion pump can lower the pressure to below 1×10^{-3} torr (1 micron). Some processes require an inert gas such as argon to be fed into the furnace at a low flowrate, allowing the pressure to rise to about 0.50 torr (500 microns) - this is called partial pressure control.

The pressure increases as the temperature rises and contaminants volatilize. Control of the vacuum is maintained at about 0.50 torr (500 microns) in partial pressure processes or below 10^{-4} torr in high vacuum processes. If the vacuum deviates from the specific set point by more than a specific value, the temperature program is held until the condition is corrected. The temperature program goes through a series of ramps and soaks. After a high temperature soak, the quench process activates and the temperature is allowed to drop. An increased flow of inert gas and circulation of cooling water in the furnace walls and heat exchanger cools the work. The cooling lowers furnace pressure, requiring additional pressure control. During the cooling, the pressure is typically controlled between 0.85 bar to 10 bar depending on process type. A light or horn usually activated as an indication to the operator that the cycle is complete. The operator then brings the furnace back to atmospheric pressure manually and unloads the product.

Control implementation

During the last 40 years of vacuum furnace manufacturing different hardware platforms for controls have been used. A common platform is based on the Honeywell HC900



The HERRING GROUP, Inc.

Professional Support Services

hybrid controller together with Experion Vista SCADA software. Features of this package can be described as follows:

Salient features of the Honeywell HC900 Experion Vista process controller

The HC900 Hybrid Controller combined with Experion Vista interface (Fig. 17) meets all of the requirements for safe and productive process operation with maximum operator convenience including:

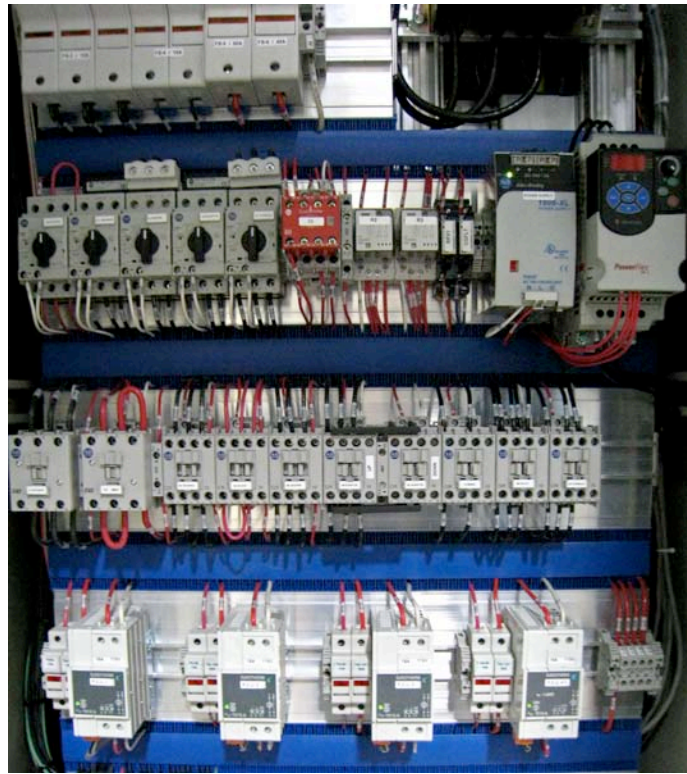
- Program control of sequencing and variables versus time
- Proportional (PID) modulating loop control
- Logic functions for equipment and process status
- Alarm detection, annunciation, and logging
- Data acquisition and data logging
- Recipe configuration, local storage and download capability
- Easily programmable by operators in engineering units.
- Sixteen (16) programmable events for integration with sequence control functions.
- Alarms and events may be programmed to send an e-mail message.
- Modbus/TCP protocol allows interfacing to HMI, data acquisition and OPC server software.
- Ethernet port supports direct PC connection or external Modem connection for configuration upload, download and maintenance.
- Isolated, universal analog inputs allow mix of analog input types on same card, saving I/O cost
- Auto tuning and fuzzy overshoot protection for quick start-up and proper control operation
- Storage of up to 1000 recipes for fast, error-free product selection
- Storage of up to 1000 time/temperature profiles. Each profile may be part of a recipe.
- Any HC900 can support up to 8 peer controllers for exchange of analog or digital data over Ethernet.



The HERRING GROUP, Inc.

Professional Support Services

Figure 17
Control Panel Assembly HC900 Experion Vista Process Controller



Example of a Vacuum Furnace Equipped with a Honeywell HC900 System

Control of temperature is executed with a powerful algorithm set that satisfies the most application requirements. Multiple tuning constants may be used to tailor the control response to the dynamic characteristics of the furnace.

Approach limits allow maximum heating rates without overshoot, reducing cycle time and optimizing efficiency. The HC900 integrates the setpoint programmer, loop and logic functions within a single device. The Setpoint Program capability of the HC900 is used to control the temperature profiles with up to 1000 different profiles appropriate for a wide range of products, can be created and stored for use when these products are processed.

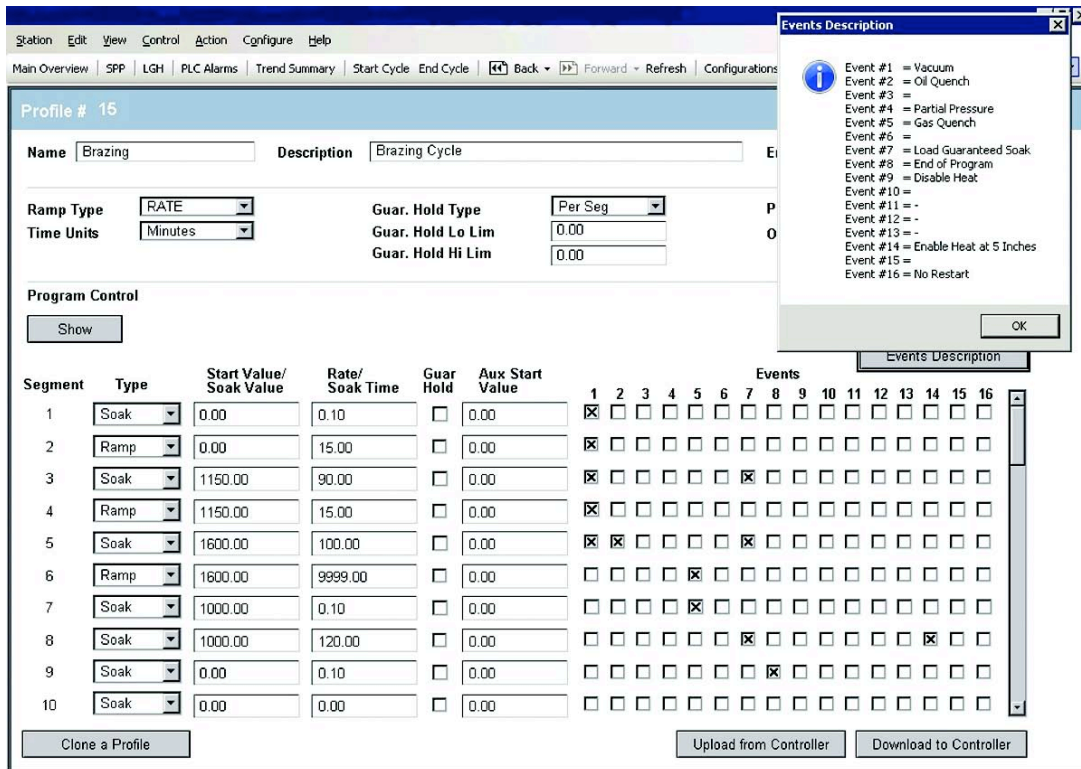


The HERRING GROUP, Inc.

Professional Support Services

A typical heat treat cycle profile (Fig. 18) uses load guarantee soak function (as event 7) to control critical soak temperature. The cycle profile also contains other events used to control diverse functions required by a heat treatment cycle (high and low vacuum level, partial pressure, quench, etc.).

Figure 18
Typical Vacuum Brazing Cycle Profile



A single configurable database integrates both the loop (proportional, modulating) functions and the logic (discrete, boolean) functions required by the process. User-friendly operator displays provide the operator with dynamic information about the status of each run as it progresses. Alarms are announced in color on dedicated displays and can be acknowledged directly from the operator interface.



The HERRING GROUP, Inc.

Professional Support Services

The complete operation can be monitored and controlled from the display screens. Standard and customized displays make it simple for operators to learn and use the system (Fig. Nos. 21 - 28).

Figure 20
Operator Interface Main Overview Screen

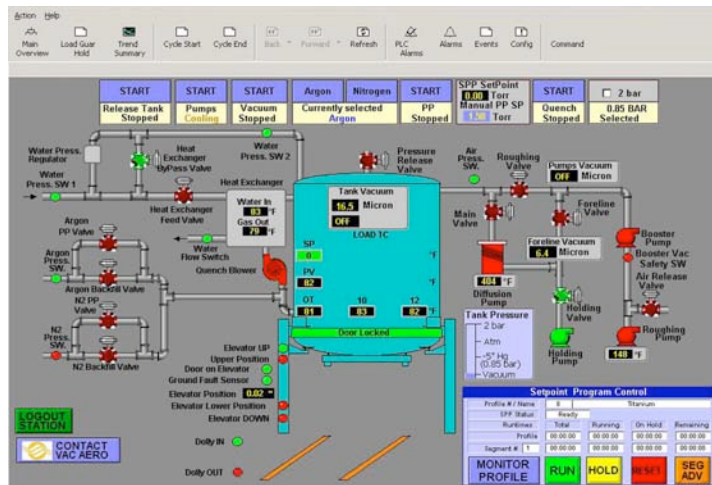
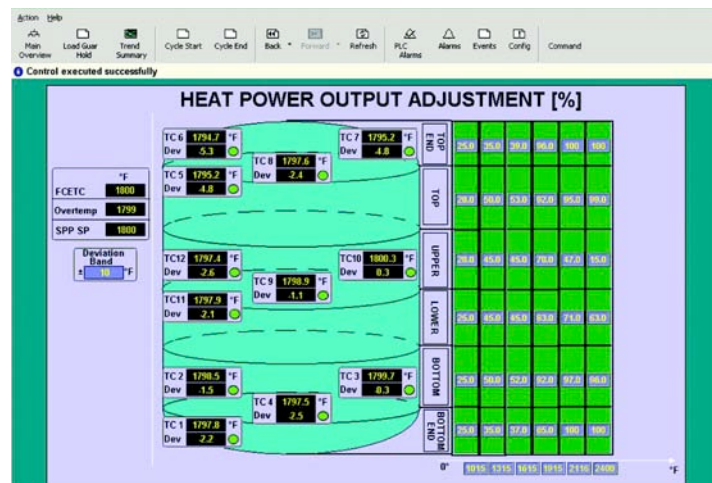


Figure 21
Heat Power Adjustment Screen





The HERRING GROUP, Inc.

Professional Support Services

Figure 22
Load Guaranteed Hold Configuration Screen

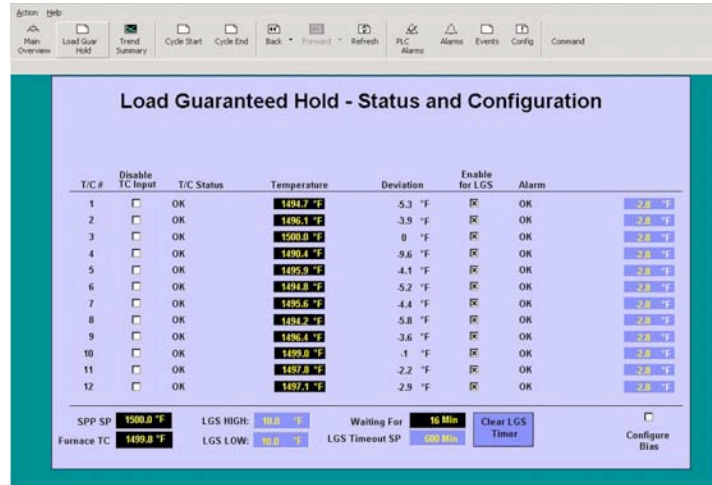
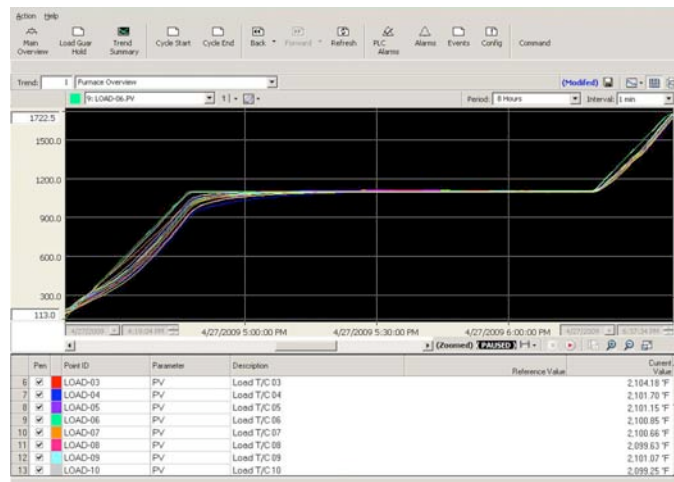


Figure 23
Trend Screen Example





The HERRING GROUP, Inc.

Professional Support Services

Figure 24
Event Log Screen

Date & Time	Location	Source	Condition	Act.	Prio.	Description	Value	Operator
11/09/2010 14:31:10	FCEB0	STATION 1	LEVEL			Security level		Mnvr
11/09/2010 14:31:10	FCEB0	STATION 1	LOGIN					
11/09/2010 14:23:45	A1	DEVL0AD12	RSLO	J:00		Deviation TC12	-1.00	°F
11/09/2010 14:23:45	A1	DEVL0AD11	RSLO	J:00		Deviation TC11	-1.00	°F
11/09/2010 14:23:45	A1	DEVL0AD10	RSLO	J:00		Deviation TC10	-1.00	°F
11/09/2010 14:23:45	A1	DEVL0AD9	RSLO	J:00		Deviation TC9	-1.00	°F
11/09/2010 14:23:45	A1	DEVL0AD8	RSLO	J:00		Deviation TC8	-1.00	°F
11/09/2010 14:23:45	A1	DEVL0AD7	RSLO	J:00		Deviation TC7	-1.00	°F
11/09/2010 14:23:45	A1	DEVL0AD6	RSLO	J:00		Deviation TC6	-1.00	°F
11/09/2010 14:23:45	A1	DEVL0AD4	RSLO	J:00		Deviation TC4	-1.00	°F
11/09/2010 14:23:45	A1	DEVL0AD2	RSLO	J:00		Deviation TC2	-1.00	°F
11/09/2010 14:23:45	A1	DEVL0AD5	RSLO	J:00		Deviation TC5	-1.00	°F
11/09/2010 14:23:45	A1	DEVL0AD3	RSLO	J:00		Deviation TC3	-1.00	°F
11/09/2010 14:23:45	A1	DEVL0AD1	RSLO	J:00		Deviation TC1	-1.00	°F
11/09/2010 14:23:43	A1	DEVL0AD16	RSLO	J:00		Deviation TC16	-1.00	°F
11/09/2010 14:23:43	A1	DEVL0AD15	RSLO	J:00		Deviation TC15	-1.00	°F
11/09/2010 14:17:02	A1	M12_HYD	CHANGE	J:00		Hydraulic Pump		OFF
11/09/2010 14:17:00	A1	M12_ON	CHANGE	J:00		Hydraulic Pump ON		NO
11/09/2010 14:17:00	A1	SEALD_ON	CHANGE	J:00		Seal Door Down Valve		OFF
11/09/2010 14:16:58	A1	M12_HYD	CHANGE	J:00		Hydraulic Pump		ON
11/09/2010 14:16:58	A1	SEALD_ON	CHANGE	J:00		Seal Door Down Valve		ON
11/09/2010 14:16:56	A1	M12_ON	CHANGE	J:00		Hydraulic Pump ON		YES
11/09/2010 14:12:47	FCEB0	STATION 1	BYE					
11/09/2010 14:12:27	A1	TB	CHANGE			SP	1.800	°F

Figure 25
Profile Configuration Screen

Profile # 15

Name: [] Description: [] Eng Units: []

Ramp Type: RATE Gear Hold Type: Per Seg Profile Duration: 600 minutes
 Time Units: Minutes Gear Hold Lo Lim: 0.00 Overtemp SP: 1625 °F
 Gear Hold Hi Lim: 0.00

Program Control

Segment	Type	Start Value/ Soak Value	Rate/ Soak Time	Gear Hold	Aux Start Value	Events	Events Description
1	Soak	0.00	0.10	<input type="checkbox"/>	0.00	<input checked="" type="checkbox"/>	
2	Ramp	0.00	15.00	<input type="checkbox"/>	0.00	<input checked="" type="checkbox"/>	
3	Soak	1150.00	90.00	<input type="checkbox"/>	0.00	<input checked="" type="checkbox"/>	
4	Ramp	1150.00	15.00	<input type="checkbox"/>	0.00	<input checked="" type="checkbox"/>	
5	Soak	1600.00	100.00	<input type="checkbox"/>	0.00	<input checked="" type="checkbox"/>	
6	Ramp	1600.00	9999.00	<input type="checkbox"/>	0.00	<input checked="" type="checkbox"/>	
7	Soak	1000.00	0.10	<input type="checkbox"/>	0.00	<input checked="" type="checkbox"/>	
8	Soak	1000.00	120.00	<input type="checkbox"/>	0.00	<input checked="" type="checkbox"/>	
9	Soak	0.00	0.10	<input type="checkbox"/>	0.00	<input checked="" type="checkbox"/>	
10	Soak	0.00	0.00	<input type="checkbox"/>	0.00	<input checked="" type="checkbox"/>	

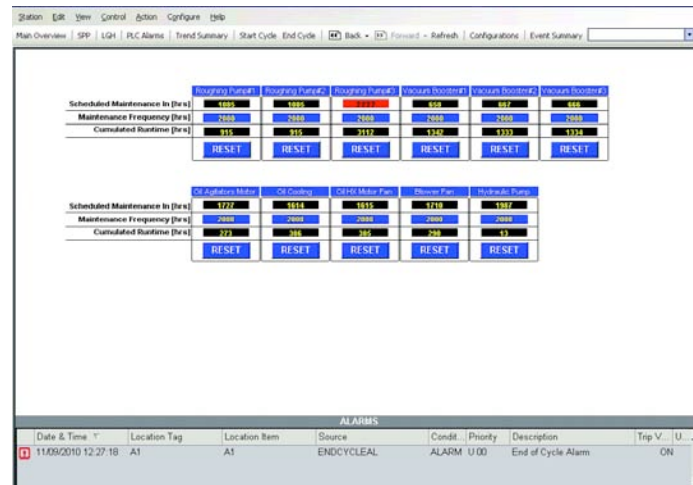
11-Sep-10 12:27:18 A1 ENDCYCLEAL ALARM U 00 End of Cycle Alarm ON



The HERRING GROUP, Inc.

Professional Support Services

Figure 26
Maintenance Timers Screen



Data Collection and Storage.

The supervisory system provides many built-in reporting functions. Standard alarm and report functions include:

- Alarm / Event Log reports all alarms and events in a specified time period.
- Alarm Duration Log reports the time of occurrence and elapsed time before return-to-normal for specific alarms in a specified time period.
- Alarm Pager (optional). Setpoint alarms may be sent to an alarm paging or messaging system.
- Integrated Excel reporting provides the ability to launch a report built using Microsoft Excel.
- Batch reports collect history for points and events that occurred during a process production run. Static batch data may also be added to the report such as batch number, customer name, lot size, etc.
- Bar-coded data functionality may be used to enter batch information.
- Reports may be generated periodically, or on an event-driven or demand basis. Report output may be directed to screen, printer, file, or directly to another computer for analysis or viewing electronically.



The HERRING GROUP, Inc.

Professional Support Services

- History collection is available over a wide range of frequencies in both average and snapshot/production formats. A large amount of history can be retained on line, with automatic archiving allowing retention of and access to unlimited quantities of historical data.
- Flexible trend configuration allows trends to be configured. Real-time and historical data are presented together on the same trend.
- The data storage feature can be used to log process information during the cycle to an internal hard drive disk or to a plant network storage device for a permanent record.

Summary

The Honeywell HC900 control system is capable of being used in an "industrial shop" environment and numerous systems are operating in the field. The software has been optimized to anticipate all normal operating and alarm conditions. The software also provides Supervisory Control and Data Acquisition (SCADA) using a touch screen LCD for operator interface for features such as:

- Compatibility with plant wide SCADA and network integration.
- Process cycle validation.
- Extensive alarm and event management and reporting.
- Temperature control using advanced algorithms, auto tuning, and multiple zone digital trimming.
- Operator sign-on/sign-off security to limit operator control of individual functions.
- Enhanced maintenance and troubleshooting management.
- Extensive set of advanced algorithms for maximum process performance
- Open Ethernet connectivity via Modbus/TCP protocol that provides plant wide process access and data acquisition
- Extensive equipment diagnostic and monitoring to maximize process availability

Ipsen talks about ... Control Innovations ^[1]

Allen Bradley's PanelView's operator terminal offers electronic interface solutions in a variety of sizes and configuration. Each system is capable of providing process information over a variety of communication protocols by Ethernet, ControlNet,

Page 33 of 51



The HERRING GROUP, Inc.

Professional Support Services

DeviceNet, DH+, DH 485 and RS-232-C to name a few. Most are offered in touch screen or keypad, and include tools such as alarming, quality imaging, and data trending.

Siemens technology, more widely used in the European market, continues to grow in popularity here in the United States. For example, S7 PLC products offer very fast scanning rates and networking capabilities with RS-232, RS-485, Profibus-DP, and MPI protocols. Siemens also provides a various range of touch screens and pushbutton interfaces for machine operation. There is a strong force overseas that steers many American “sister” companies to use Siemens controllers. However, acceptance for these controls is a concern for engineers and maintenance personnel more familiar with other products. However, Siemens continues to expansion into the heat treat industry lessening these concerns.

Honeywell also has dedicated product lines specifically for temperature and process control. Their UDC temperature controllers have a proven track record for temperature control. The PLC merely sends the set point to the UDC controller and the UDC takes over control from there. Honeywell also has its own modular controller (UMC 800 – Universal Multiloop Controller) that addresses the analog and digital control requirements of small unit processes. Using its strong algorithmic background for PID control, it combines PLC function block programming for machine functionality. This is an ideal solution for small furnaces with limited input/output (I/O) needs. The UMC 800 provides integrated loop and logic control.

For simpler vacuum furnaces that don’t require the power of a PLC, a Digital Control Processor (DCP), such as Honeywell’s DCP550 can run a furnace program. Given 99 programs with 99 segments, ramp rate, soak set point, soak time, and events are all parameters that can be entered and run within this controller. From there, its P.I.D. loops maintain certainty between the temperature setpoint and the furnace control thermocouple.

The method of controlling basic vacuum furnace process parameters has changed over the years. PLC controls tied to versatile HMI’s are doing the job that previously required several devices.

Frequently, external temperature controllers are used for adjusting the heat on vacuum furnaces even though the control is offered within the PLC. Properly tuning P.I.D. control within the PLC can be very troublesome. With better P.I.D. algorithms being



The HERRING GROUP, Inc.

Professional Support Services

developed and proven by PLC manufacturers, coupled with the option to eliminate the external temperature controller, greater P.I.D. functionality will be realized within the PLC in the near future.

Cooling for a vacuum furnace is another important variable that must be addressed. Two types of controlling normally exist: uncontrolled and controlled. Uncontrolled cooling simply depends on the heat retained in the parts. Then, it's just a matter of time until either the furnace, or parts (work thermocouples) are brought to a satisfactory temperature under the correct pressure to continue or end the process. Controlled cooling allows the parts to be cooled at a specified rate in order to obtain desired end results. By means of a Variable Frequency Drive (VFD) to control the speed of the cooling fan, or a variable (damper) valve, the amount of cooling gas introduced into the furnace chamber can be monitored and controlled through precise adjustments made by the PLC controller.

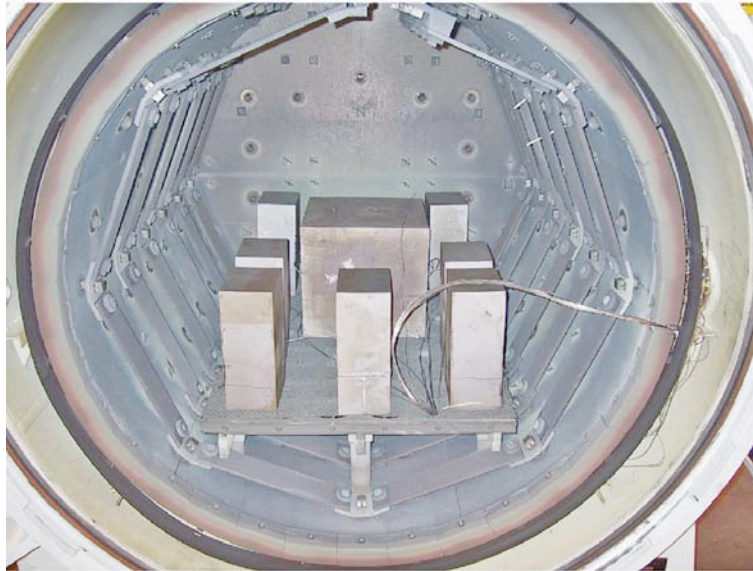
Isothermal hold is an option normally used when heat-treating large parts such as dies while controlling distortion and avoiding cracks (Fig. 27). Coupled with controlled cooling, it allows control of the quenching process more accurately. By taking a thermocouple's reading on the inside of the part and comparing it to thermocouple on the outside of the part, heat treaters are able to monitor the difference between the two thermocouples. With this calculation, cooling can be controlled so that the difference between the two thermocouples does not exceed a bandwidth requested by the operator. Thus, a more uniform, controlled quench is achieved.



The HERRING GROUP, Inc.

Professional Support Services

Figure 27
Large Die Blocks Inside a Vacuum Furnace



Multiple thermocouples placed in a tray or basket in different areas with the parts allow monitoring of the temperature spread or uniformity throughout the load. Each thermocouple will give a temperature reading (Fig. 28). Cooler or hotter areas within the furnace can be visible at different locations.

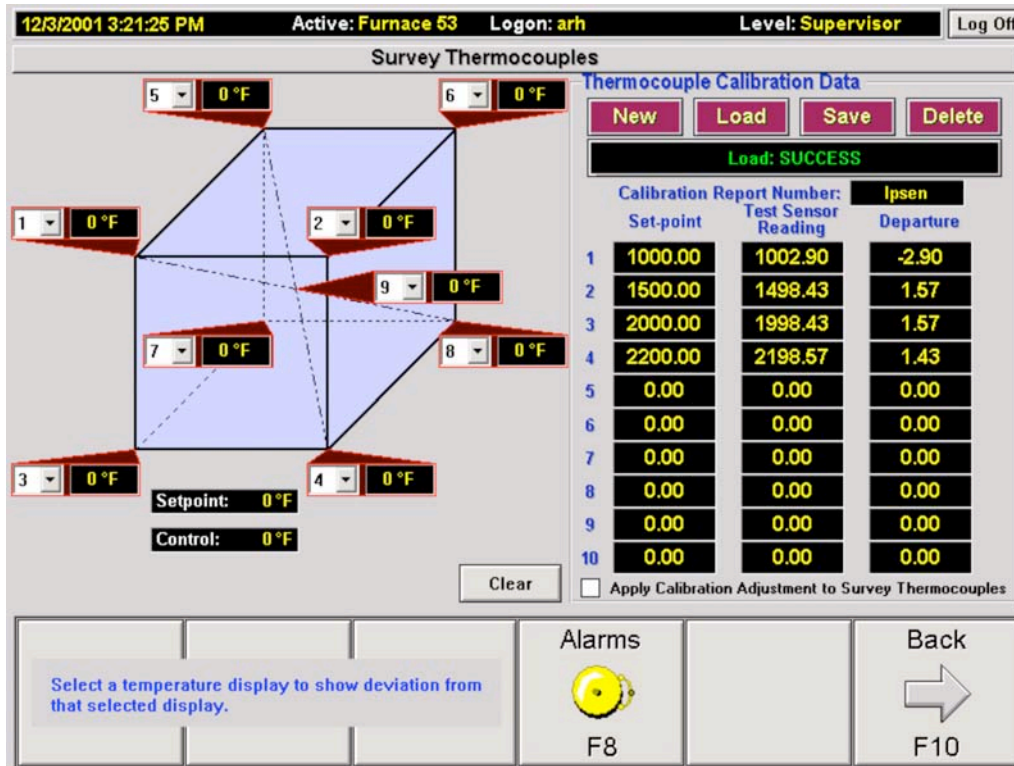
Convection heating is a desirable choice for heat treaters that have dense or irregular shaped loads. Heat will find all surface areas of a part when the heat is circulated by a fan in the furnace through a positive pressure medium. Convection also reduces the heating time and may reduce distortion.



The HERRING GROUP, Inc.

Professional Support Services

Figure 28
Thermocouple Survey Screen



Cycle time for a particular load is simply based on the ramp rate or soak time that is specified in the recipe at a certain temperature. The soak time starts when temperature set point has been reached or within a bandwidth specified by the operator. Timers maintain the temperature within said bandwidth for the amount of soak time specified.

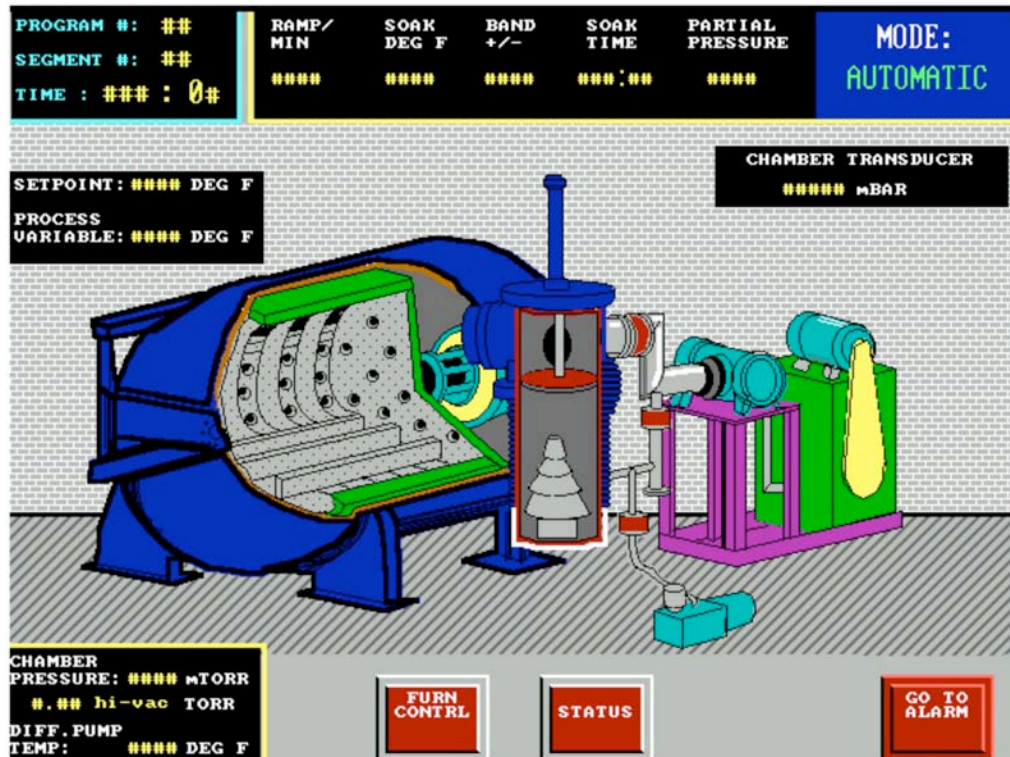
Another variable that can be controlled is the pressure inside the vessel. Using appropriate gauging for the vacuum levels required, valves can be opened and closed as needed in conjunction with a pumping system to give us an accurate and acceptable level. Switches and transducers are used for monitoring these levels for a positive or negative pressure. Transducers offer greater flexibility for running a process at several different ranges of pressure.



The HERRING GROUP, Inc.

Professional Support Services

Figure 29
Graphical Overview of a Vacuum Furnace



Graphical interfaces at the furnace or at a remote location provide easy to understand information on what the furnace is doing (Fig. 29). CTC Parker Automation, Allen Bradley's PanelView interfaces and Siemens OP terminals, are just a few of the many HMI's well known in the heat treating industry to monitor, record, and store machine variables as needed. Visual representations of the status of valves, motors, pump, fans, etc. can be displayed. Color change or simple animation of main components on a furnace can provide information not readily seen on the furnace exterior. Having detailed information in graphical format along with other important readings from the furnace can be very informative at a quick glance.

Other screens are also helpful by way of displaying specific data such as I/O (input/output) status of the PLC. Real-time trending and historical trending offer a



The HERRING GROUP, Inc.

Professional Support Services

comparative tool to help improve processes or determine machine repeatability. It is a tool that allows us to see the differences and effects that specific loads or programs have on a cycle. Maintenance screens give information on hourly usage of motors, pumps, of other systems so that a maintenance schedule can be created and followed, extending the life of each component (Fig. 30). Operator screens can also give us detailed alarms at the time of occurrence.

Figure 30
Sample Preventative Maintenance Screen

The screenshot displays a 'Preventive Maintenance' screen for 'Furnace 53'. At the top, it shows the date and time '12/3/2001 3:22:03 PM', the active furnace 'Furnace 53', the user 'Logon: arh', and the user level 'Level: Supervisor'. A 'Log Off' button is in the top right corner. The main area is a grid of six columns, each representing a component: Roughing Pump, Vacuum Booster, Gas Blower, Hot Zone, Holding Pump, and Diffusion Pump. Each column contains: 'Actual Hours' (displaying '0'), a 'Reset' button, 'Parameters' (Preset: 0, Service Required radio button), 'Offset' (displaying '0', Service Required radio button), and 'Days' (displaying '0'). Below the grid are three buttons: 'PLC Rack' (with an icon and 'F5'), 'Alarms' (with a yellow alarm icon and 'F8'), and 'Back' (with a right arrow icon and 'F10').

Recipe creation provides the operator or supervisor with the means to enter values, ramp rate, soak temperature, soak time, associated events for a furnace to run its cycle automatically. Once the recipe is created, cycle start is the only other button needed to run the furnace, after which all functions are automatic. When the recipe has finished,



The HERRING GROUP, Inc.

Professional Support Services

data can be interpreted from graphs or trends to verify furnace control followed the instructions entered within the recipe.

Supervisory monitoring/limited control is becoming increasingly popular. Remote systems are ideal for data collection and real-time information purposes. Wonderware's Intouch package is a prime example. Recipes for loads can be stored and created remotely, graphics can show machine systems running to individuals in a different location, and information can be saved to various databases or plant networks for backup. These systems give heat treaters increased versatility and expandability. Several machines or entire lines throughout a plant can be connected to one supervisory PC that monitors and collects all machine variables. These systems can also manage and optimize workflow throughout a plant with proper part tracking tools. Utilizing the capabilities of such networked system keep heat treatment on the leading edge of this communication revolution.

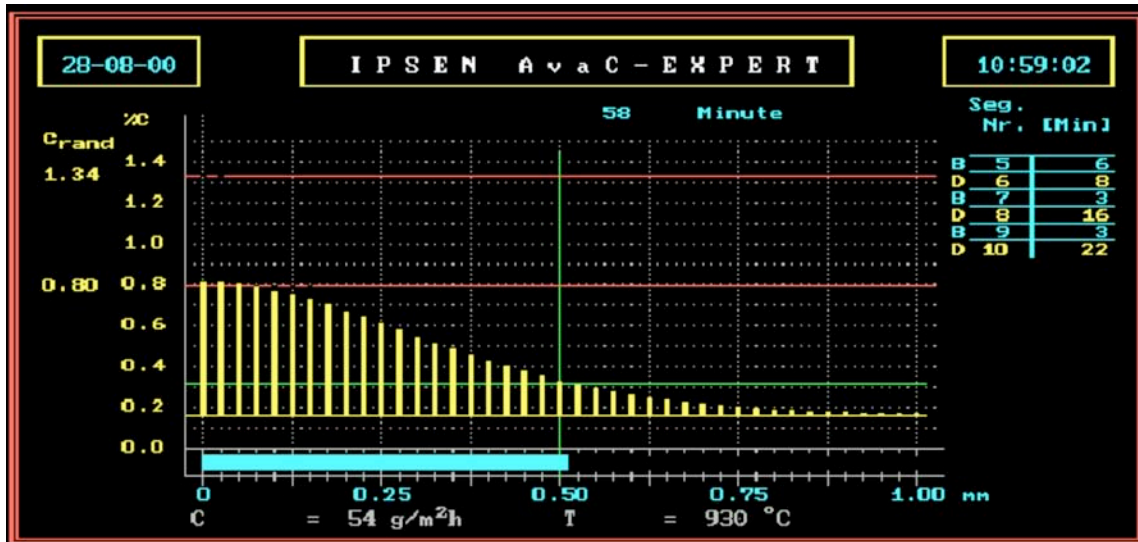
Predictive software that calculates or simulates process cycles is available today (Fig. 31). Enter the hardness level required, the material to be treated, and the required case depth (in the case of atmosphere or vacuum carburizing) allows the software to generate the required recipe to achieve the requested results. This is very beneficial for heat treaters that heat-treat several types of parts. Once the recipe is generated, this information can be sent to the furnace's control system for execution. Material results can then be compared with the cycle ran, giving a metallurgist the abilities to improve or adjust parameters if needed.



The HERRING GROUP, Inc.

Professional Support Services

Figure 31
Simulation Software



SECO/WARWICK Corporation talks about ... New Vacuum Furnace Control Systems

Control systems that are both intuitive and easy to operate are at the heart of today's industrial heating equipment. SCADA based control systems are standard on many vacuum furnaces with PLC's, Industrial PC's with touch screen and visualization software making up the human-machine interface.

Control packages based on Wonderware InTouch[®] such as SecoVac[®] offer software tools to simplify daily use including production management, process programming; collecting and safe storage of batch data; process reporting; reminders of basic maintenance operations and troubleshooting capability.

It is important for a vacuum furnace manufacturer to have a dedicated programming team intent on continuously improving the control systems and to look at system help screens and on-screen tips; switching between different engineering units and operator languages; GSM text messaging system; full process and batch reporting; verification of process recipe; timed process launch; online recipe edition; PID auto tune and much more.



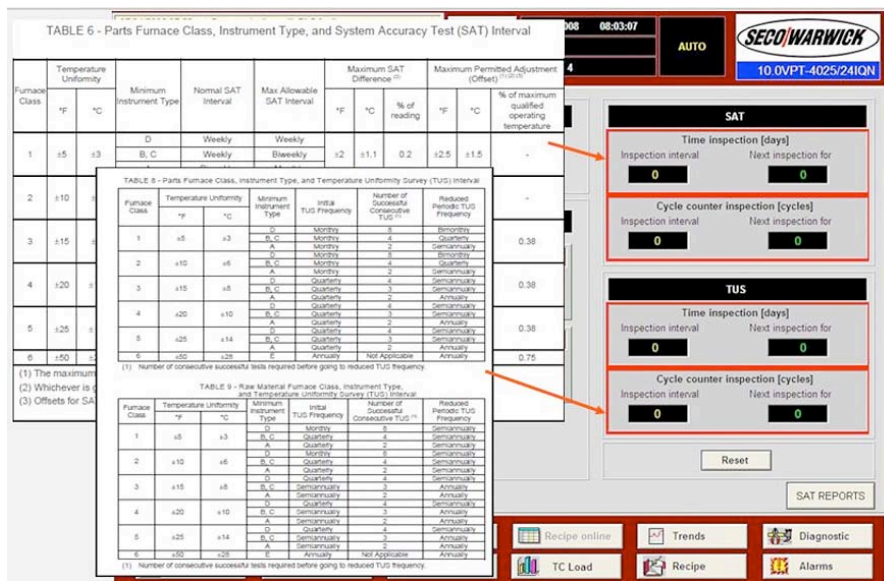
The HERRING GROUP, Inc.

Professional Support Services

Using Ethernet network to communicate PLC and HMI, these furnaces can be integrated in an office network. This creates extensive possibilities in areas of data acquisition, production management and supervision of processes and equipment. It allows integrating furnaces with company ERP system in order to gather all information about products from different stages of production process in one safe place.

Industry regulations and aerospace specifications software should incorporate operations required by AMS2750D into the furnace control system (Fig. 32). TUS and SAT support, with multi-point correction factors and offsets for all temperature sensors and thermocouple-life-counters are important features to include.

Figure 32
Support for AMS 2750D Pyrometry Requirements.



System Accuracy Test (SAT) became more important with revision D of AMS2750. It is important suppliers offer upgrades to software packages for vacuum furnaces to support these changes.



The HERRING GROUP, Inc.

Professional Support Services

Smart control systems can remind users about a scheduled test, collect data from furnace and test instrument via industrial communication interfaces, provide maintenance reminders and can even create and store complete SAT reports that meet requirements of Nadcap documentation. After completion of testing, recorded data can be compared and results can be calculated. Complete report can be printed or stored in internal database. It is easy to organize and quickly available during audits (Fig. 33).

Control systems allow for entering temperature offsets at several stages for each control thermocouple according to SAT results. Those offsets are independent from correction factors taken from sensor's certificate of calibration.

Figure 33
SAT Report Preview

System Accuracy Test (SAT)
Calibration report

Report date: 2008-08-19 12:39
Furnance: VTR-5050/216HV
Specifications: AMS2750
Test instrument: Fluke S/N 25346346
Test sensor: 3I244

	Control zone #1		
	Indicator	Recorder	Load sensor
Date/Time	2008-08-02 15:32	2008-08-02 15:32	
Set temperature	920°F	920°F	
Instrument indicated or recorded Temp.	A 921.4°F	919.0°F	
Correction	B None	None	
A + B = C	C 921.4°F	919.0°F	
Test instrument reading	D 919.8°F	919.8°F	
Test T/C correction factor	E -1.6°F	-1.6°F	
Test instrument correction factor	F -0.6°F	-0.6°F	
True temperature D + E + F = G	G 917.6°F	917.6°F	
SAT difference C - G	3.8°F	1.4°F	
Result	Fail(1)	Pass	
Technician	RK	RK	

Notes: (1) Test result do not meet requirements. SAT Difference exceed maximum allowable 3°F

SAT reporting can provide the following information:

- Test sensor identification.
- Test device identification.
- Checked sensor identification.
- Date/hour of test.



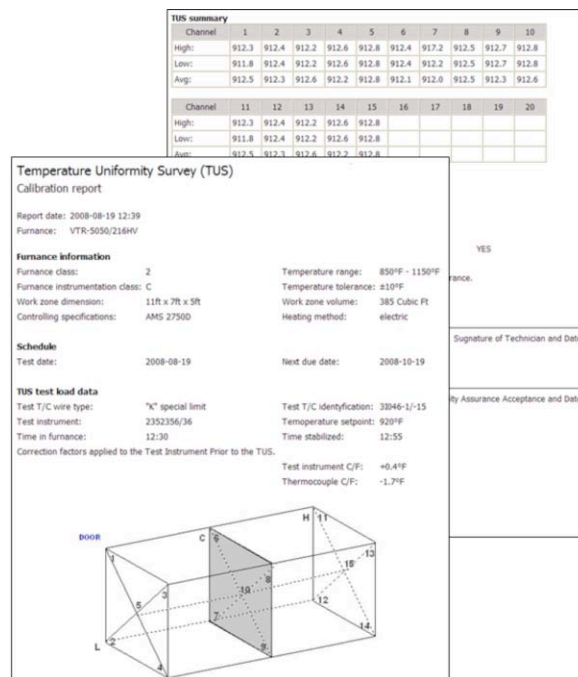
The HERRING GROUP, Inc.

Professional Support Services

- Monitoring device reading.
- Test device reading.
- Adjusted test device reading.
- Computed variation of system accuracy.
- Identification of the test-performing technician.
- Indication of acceptance or rejection of the test.
- Report notes.

Temperature Uniformity Surveys should be performed monthly for most of furnaces (e.g. Class 1 & 2). SecoVac can also support customers in this endeavor, with a SAT, TUS module (Fig. 34) that also has reminder features, data acquisition and reporting (Fig. 35).

Figure 34
TUS Report Preview

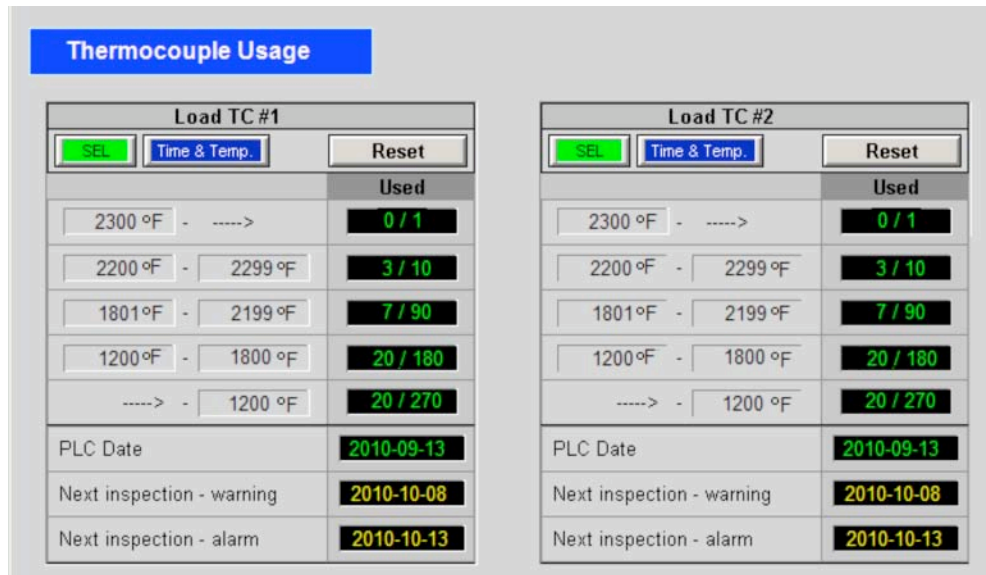




The HERRING GROUP, Inc.

Professional Support Services

Figure 35
TUS Tool Windows



TUS reporting can include following information:

- Device identification.
- Device class.
- Temperature range.
- Acceptable temperature variation.
- Dimensions and volume of the operation space.
- Specification used.
- Heating method.
- Date and time of start and end of each test.
- Measuring element type.
- Measurement device type.
- Temperature set point.
- Thermocouple layout map.
- Minimum, maximum and average value for each of the measurement elements.
- Confirmation of reset occurrence.
- Test result.



The HERRING GROUP, Inc.

Professional Support Services

- File path to the Excel file with all the measurements.
- Report notes.

TUS report capability should allow for collecting and storing data from all test sensors and furnace sensors. Test temperatures can be received from most of test recorders via industrial communication interface or attached as a data file. Correction factors for each test sensor can be applied according to certificate of calibration. After TUS completion recorded temperatures are verified and system indicates if any of point has temperature variation behind allowed limits. TUS test report can be also generated and stored on computers hard drive.

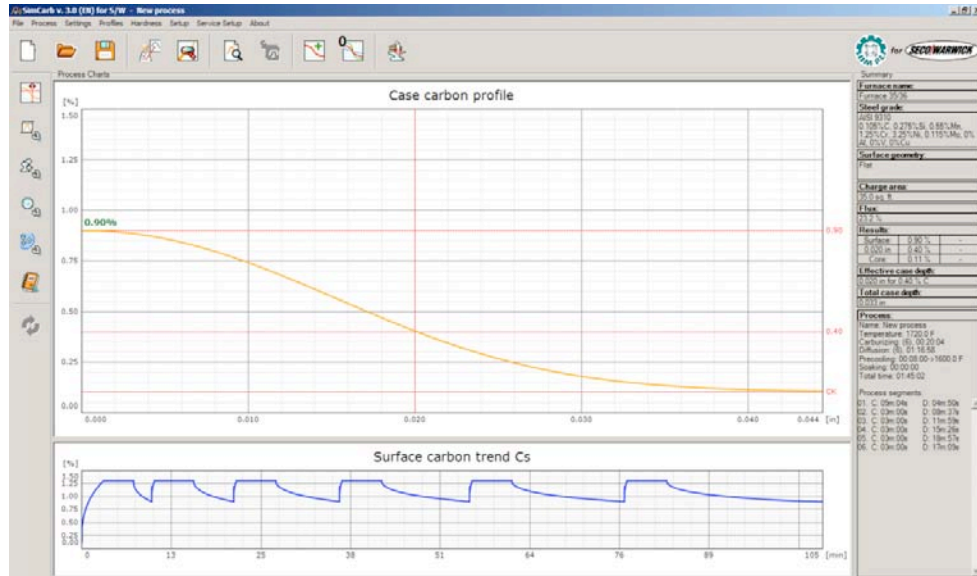
All furnaces users in aerospace industry have to track life of base metal temperature sensors and keep those records, then replace thermocouples while they are supposed to be replaced. Thermocouple usage counters (Fig. 36) are another outstanding feature of these control system. These lifetime counters keep tracking temperatures of each thermocouple, and compute them as required by AMS2750D section 3.1.8.5. Each time the sensor is exposed to certain temperature is counted along with sensor's time period. When the thermocouple is used certain number of times at certain temperature or when its maximum usage time elapsed, the operator will get the warning and then alarm message with detailed information what happened and what has to be done. This function is very useful, eliminating the human factor and reducing the number of operations, which quality/maintenance staff should do to meet code requirements.



The HERRING GROUP, Inc.

Professional Support Services

Figure 36
Thermocouple Usage Counters



Low pressure carburizing (LPC) simulation software (SimVac®)

New vacuum carburizing technologies introduced by R&D groups such as FineCarb® Low Pressure Vacuum Carburizing technology includes a simulation software tool that supports them in process parameterization. SimVac® software determines the carburizing process parameters according to specified carbon case parameters.

The application allows the user to define the steel grade, part geometry and select the material or process specifications such chemical composition and quenching temperature. This information is then used for further calculations of cooling speeds based on the physical properties of treated elements as well as the mass and geometry of the charge. As the result of simulation, user gets proposed heat treat recipe along with graphic representation of carbon profile.



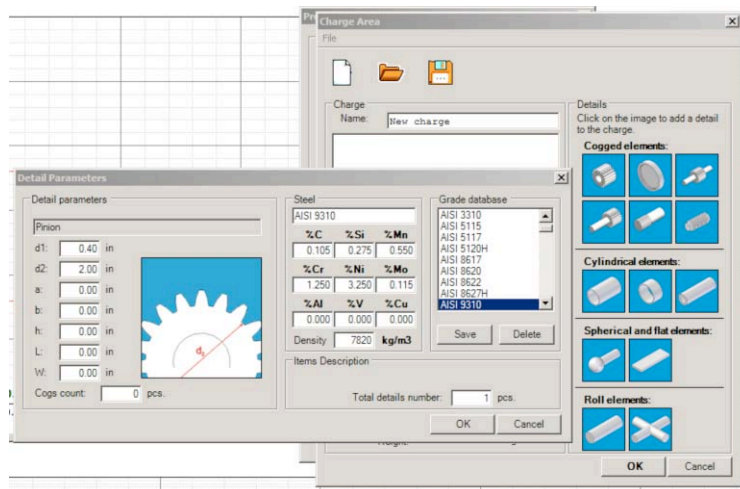
The HERRING GROUP, Inc.

Professional Support Services

Results of simulations can be printed and attached to the batch report and created recipe can be easily transferred to SCADA systems such as SecoVac[®]. This software has a build-in database of steel grades according to different international standards. Customer can also define different steel grades if needed. A database of basic shapes of parts (Fig. 37) allows the software to estimate the surface area of the batch. Active surface area is an important parameter for vacuum carburizing processes as far as amount of carbon gasses supplied to the chamber.

New software packages can now predict the hardness profile of carburized and gas quenched parts. (Fig. 38). Determining the cooling speed at a particular distance from the surface is necessary to calculate hardness profile in the carburized layer of a particular geometry. This module also takes to consideration different cooling ability of individual furnace types at different pressures of quenching gas. After simulation completion, the user receives predicted hardness profile with suggested heat treat recipe.

Figure 37
Database of Basic Shapes is built in Simulation Software

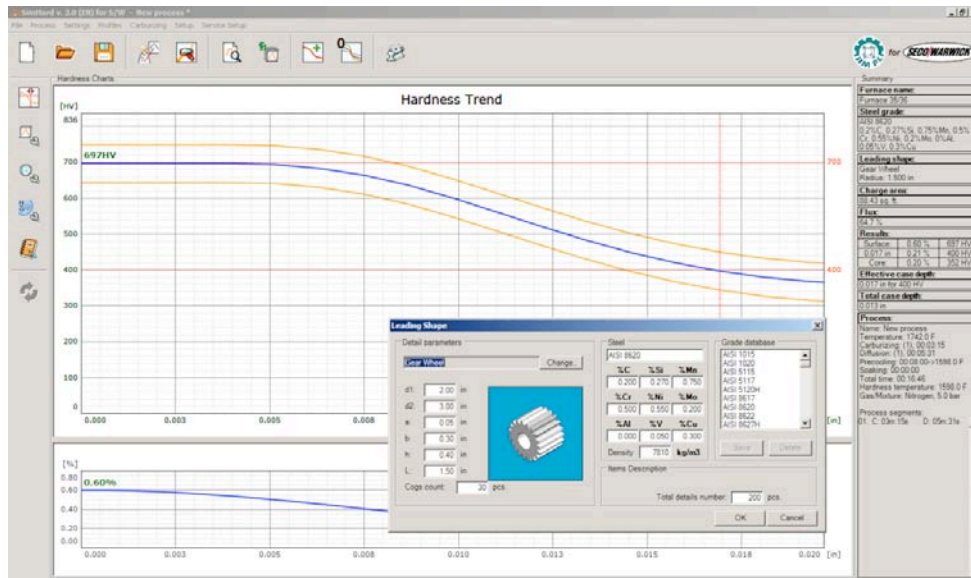




The HERRING GROUP, Inc.

Professional Support Services

Figure 38
Hardness Simulator to Determine the Hardness Profile



Solar Atmospheres Talks About the Future of Instrumentation and Controls...

Over the past 10 years instrumentation for vacuum furnaces has experienced a major change from stand alone analog toward integrated microprocessor based instrumentation at an ever-increasing rate. For process control, relay logic, has long since been replaced with microprocessor based programmable logic control. Today, newer control panel's feature touch screen interactive controls to operate vacuum pumps, control valves, hot zone power, partial pressure control, gas backfill, quench blower motor, alarms and more. Full temperature and vacuum programs can be installed on these panels and monitored or altered via the operator. Most importantly this instrumentation can be monitored over the Internet remotely, via computer, and with proper password the process upgraded or in fact changed.

Vacuum gauges have seen a similar transition away from meters to digital read out and microprocessor based controls allowing vacuum scales stretched from atmosphere to high vacuum over hundreds of decades of pressure range unheard of years ago. Newer vacuum gauges are corrected for residual atmosphere, for example hydrogen or argon, and now



The HERRING GROUP, Inc.

Professional Support Services

operate on an absolute pressure basis. Already available are “smart vacuum gauge heads” eliminating a vacuum gauge controller reading out directly to a panel view and logging directly to data collection.

Probably the most useful change is in recorders. Gone are strip chart recorders and retaining a mountain of charts and chart coping. Today, data collection is digital and stored on central computers, available for quality control or transmission to the customer over the Internet.

The next 10 years will see additional changes hard to visualize as microprocessors and computers advance further. This means smaller, more easily assessable, portable, probably voice actuated, and at lower cost with more uses and capacity. However, instrumentation will become outdated faster, meaning obsolesce, as manufacturers will not support older models forcing heat-treating operations to invest in the future. A major trend is and will be increasing dependence on electronic control and instrumentation to take control away from human operators to avoid costly mistakes with workloads costing thousands if not tens of thousands of dollars (or more).

Final Thoughts from "The Heat Treat Doctor"

It is natural to ask what vacuum furnace control systems will evolve to in the future? What we know for sure it that customers are emphasizing the need for accurate data collection and archiving services. Information produced by a machine must be available at any time, and in real time if at all possible. Furnaces must have the ability to be networked, yet operate independently.

Whatever type of control is used, the data must be accessible through a remote or networked system. By analyzing this information from virtually anywhere, including hand held devices, heat treaters will have the ability to reduce energy and run shorter cycles with same or better results in real time. Utilization of more interactive simulators with improved feedback circuitry to predict an accurate furnace program to give repeatable cycles will become a reality. More automation will be seen in the future such as automatic loading and unloading, part tracking systems, and “lights-out” operations. We are evolving in a communication revolution and the vacuum furnace industry will not be left behind.



The HERRING GROUP, Inc.

Professional Support Services

Acknowledgment

This article could not have been made possible without the companies and individuals noted below.

Next Time: Part eighteen of this series looks at various vacuum furnace maintenance practices and procedures as well as offers tips from industry experts on what areas need to be maintained, how often, and why certain components should be inspected and/or replaced.

References

1. Hagler, Alex, *State-of-the-Art Controls for Vacuum Furnaces*, Ipsen USA, white paper.
2. Mr. Ralph Poor, Surface Combustion, Inc., private correspondence.
3. Mr. Bill Jones, Solar Manufacturing, private correspondence.
4. Mr. Rafal Walczak, SECO/WARWICK Corporation, private correspondence.
5. Mr. Alan Charky, Vac-Aero Corporation, private correspondence.