

Temperature monitoring and surveying (TUS) solutions for carburizing of automotive components

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PhoenixTM

Carburizing Process

Carburizing has rapidly become one of the most critical heat treatment processes employed in the manufacture of automotive components. Also referred to as Case hardening it provides necessary surface resistance to wear, whilst maintaining toughness and core strength essential for hardworking automotive parts. The carburizing heat treatment process is commonly applied to low carbon steel parts after machining, as well as high alloy steel bearings, gears, and other components. Being critical to product performance, monitoring and controlling the product temperature in the heat treatment process, is essential.

The carburizing process is achieved by heat treating the product in a carbon rich environment typically at a temperature of 900 - 1050°C / 1652 - 1922°F. The temperature and process time influences significantly the depth of carbon diffusion and associated surface characteristics. Critical to the process is following diffusion a rapid quenching of the product is performed in which the temperature is rapidly decreased to generate the microstructure giving the enhanced surface hardness whilst maintaining a soft and tough product core.

Increasing in popularity in the carburizing market is the use of batch

or semi-continuous batch Low Pressure Carburizing Furnaces. New furnace technology employs the dissociation of Acetylene (or propane) to produce carbon in an oxygen free low pressure vacuum environment, which diffuses to a controlled depth in the steel surface. Following the diffusion the product is transferred to a high pressure gas quench chamber where the product is rapidly gas cooled using typically N₂ or Helium up to 20 bar. An alternative to gas quenching is the use of an oil quench, used commonly in continuous carburizing furnaces where the products are plunged into an oil bath.

Temperature Monitoring Challenges in Low Pressure Carburizing

As already stated the Carburizing process success is governed by a careful control of both the process temperature and duration in the heating and quench stages. Obviously when considering temperature we are interested in the product temperature not the furnace. Measuring product temperature through a carburizing process although possible using trailing thermocouples, as performed historically, is certainly not easy, safe and disrupts production for lengthy periods.

PhoenixTM provides a superior solution with the use of a 'Thru-Process'

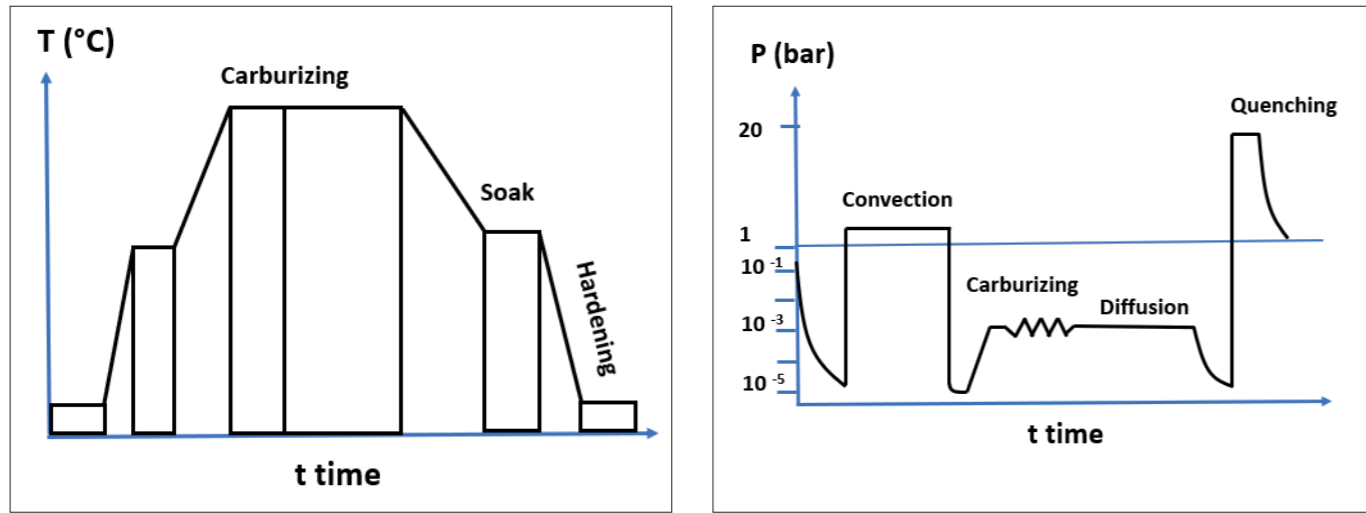


Figure 1. Schematics of the LPC Carburizing process showing the Temperature and Pressure steps



Figure 2. PhoenixTM PTM1220 20 Channel IP67 Data logger

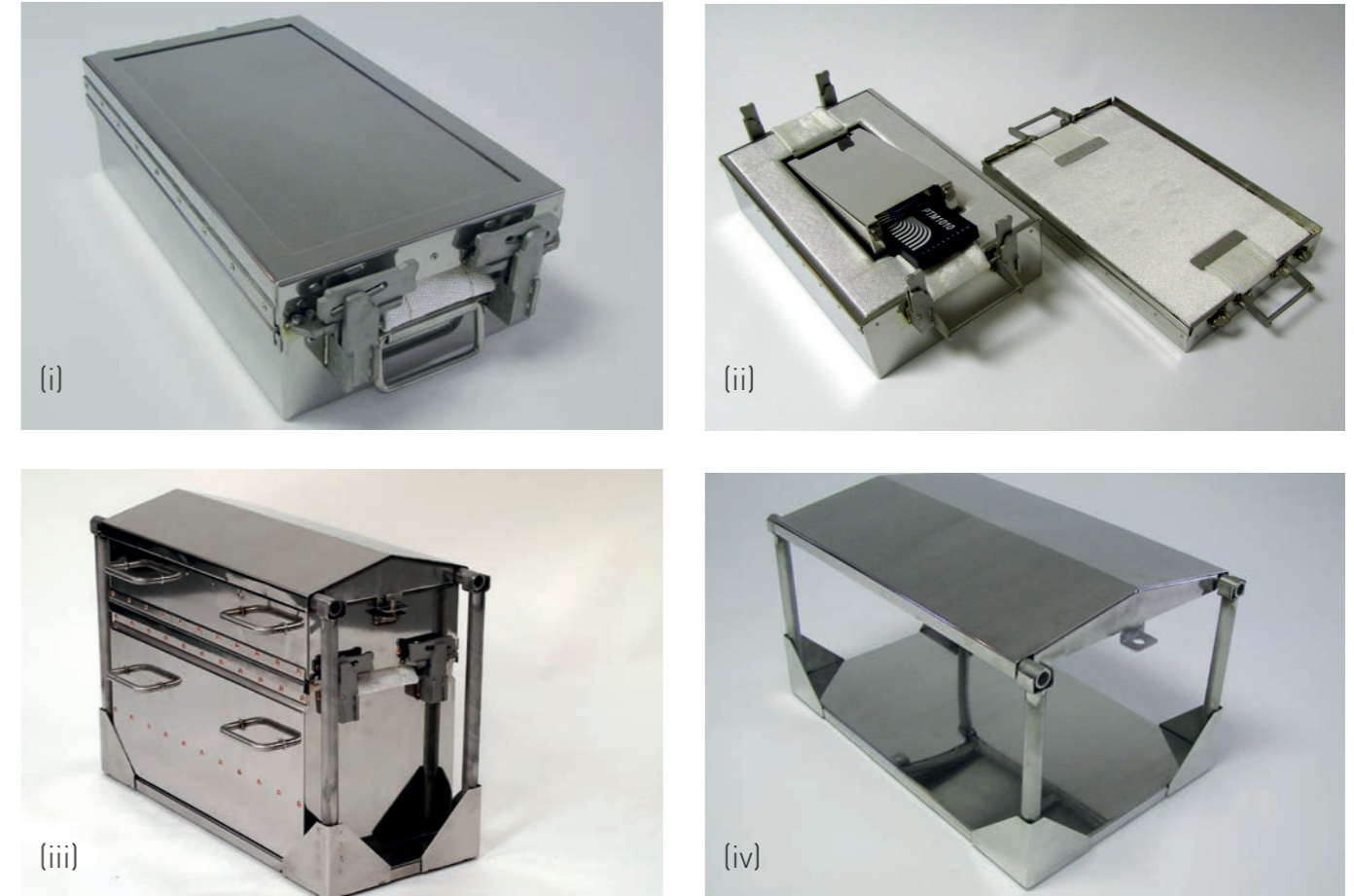


Figure 3. Thermal Barrier Designed Specifically for LPC with Gas Quench.

- (i) TS02-130 low height barrier designed for space limiting LPC furnaces with low performance gas quenches (<1 bar). Only 130mm / 5.1 inch high so ideal for small parts. Available with Quench Deflector kit. (0.9 hours @ 1740 °F / 950 °C).
- (ii) Open barrier showing PTM1220 logger installed within phase change heatsink.
- (iii) TS02-350 High Performance LPC barrier fitted with Quench Deflector capable of withstanding 20 bar N2 Quench. (350mm / 13.8 inch WQD 4.5 hours @ 1740 °F / 950 °C).
- (iv) Quench Deflect Kit showing that lid supported on its own support legs so pressure not applied to barrier lid.

temperature monitoring system. As the name suggests the PhoenixTM temperature profiling system is designed to travel through the thermal process measuring the product and or furnace environment from start to finish. The system can be incorporated into a standard production run so does not compromise productivity. A high accuracy, multi-channel data logger records temperature from thermocouple inputs, located at points of interest on, in or around the product being thermally treated. To protect the data logger as it travels through the hostile furnace a thermal barrier is employed to keep the logger at a safe working temperature to prevent damage and ensure accuracy of measurement. The barrier also obviously needs to protect during the quench whether that be against high pressure or

oil ingress, if the quench can't be avoided. Employing the PhoenixTM system a complete thermal record of the product throughout the entire process can be collected. A popular enhancement to the system is the use of 2-way RF telemetry providing real time process monitoring direct from the furnace, useful for either profiling or performing a live Temperature Uniformity Survey (TUS). The product temperature can be viewed live and downloaded at any point in the furnace. Raw temperature data collected from the process can be converted into useful information using one of the custom designed PhoenixTM Thermal View Software packages available. The thermal graph can be reviewed and analysed to give a traceable, certified record of the process performance. Such information is critical to satisfy CQI-9, AMS2750 and

other regulatory demands. Fully TUS Compliant reports can be produced in moments from the simple and intuitive software, making accurate TUS a simple and quick task. Information can be used to not only prove product quality but provide the means to confidently change process characteristics to improve productivity and process efficiency (Optimize Diffusion, Soak and Quench).

PhoenixTM Data logger Range

Data loggers can be provided in a variety of configurations to suit the specific demands of the process being monitored. Models ranging from 6 to 20 channels can be provided with a variety of thermocouple options (types K, N, R, S, B) to suit measurement temperature and accuracy demands (AMS2750 & CQI-9). Provided with Bluetooth wireless

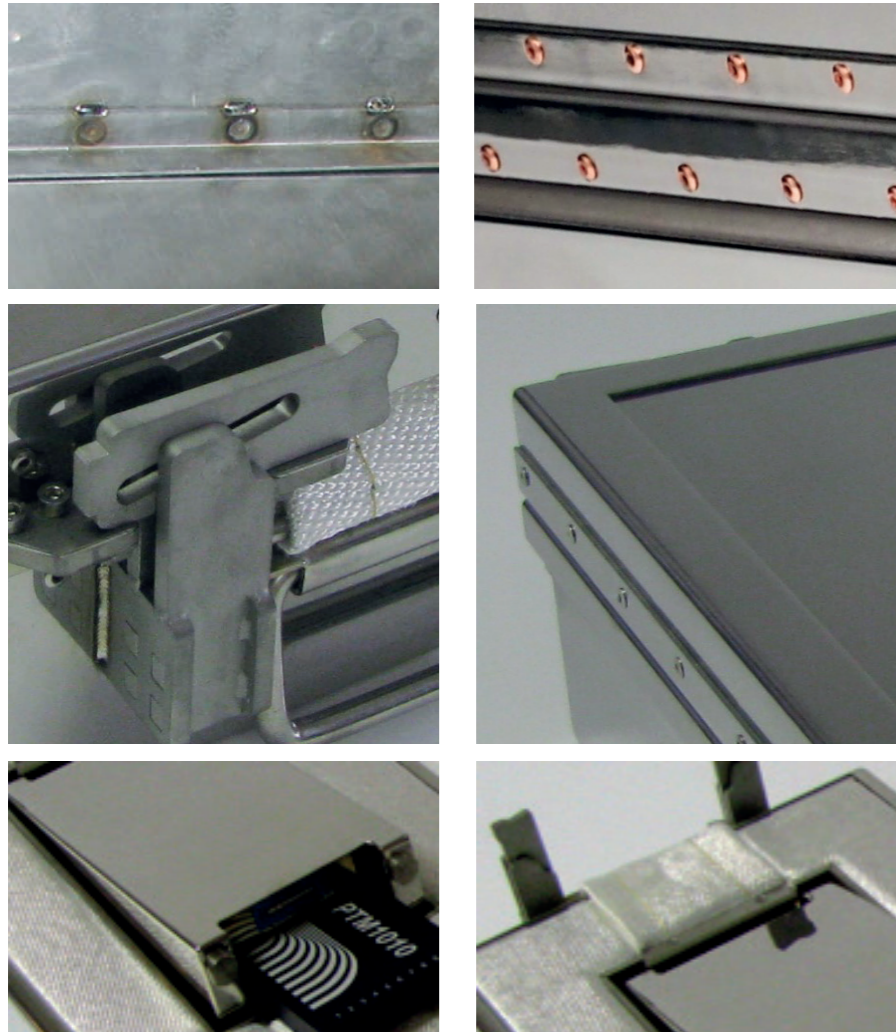


Figure 3a.

Barrier – Reinforced 316 SS strengthened and reinforced at critical points to minimize distortion (>1000°C / 1832°F HT or Ultra HT Microporous Insulation to reduce shrinkage issues)
Close pitched Cu Plated Rivets (Less Carbon Pick Up) reducing barrier wall warpage

High temperature heavy duty robust and distortion resistant catches. No thread seizure issue.

Barrier lid expansion plate reduces distortion from rapid temperature changes.

Phase change heat sink providing additional thermal protection in barrier cavity.

Dual probe Exits for 20 probes with replaceable wear strips. (low cost maintenance)

Figure 4. Oil Quench Barrier Design Concept Schematic

- (i) Sacrificial replaceable insulation block replaced each run,
- (ii) Robust outer structural frame keeping Insulation and Inner barrier secure.
- (iii) Internal completely sealed Thermal Barrier.
- (iv) Thermocouples exit through water / oil tight compression fittings.

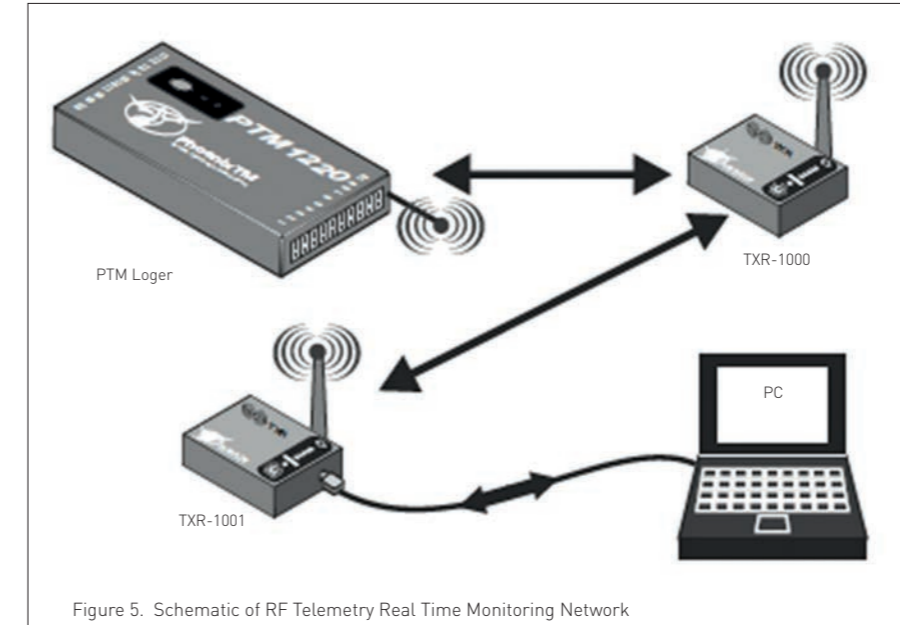
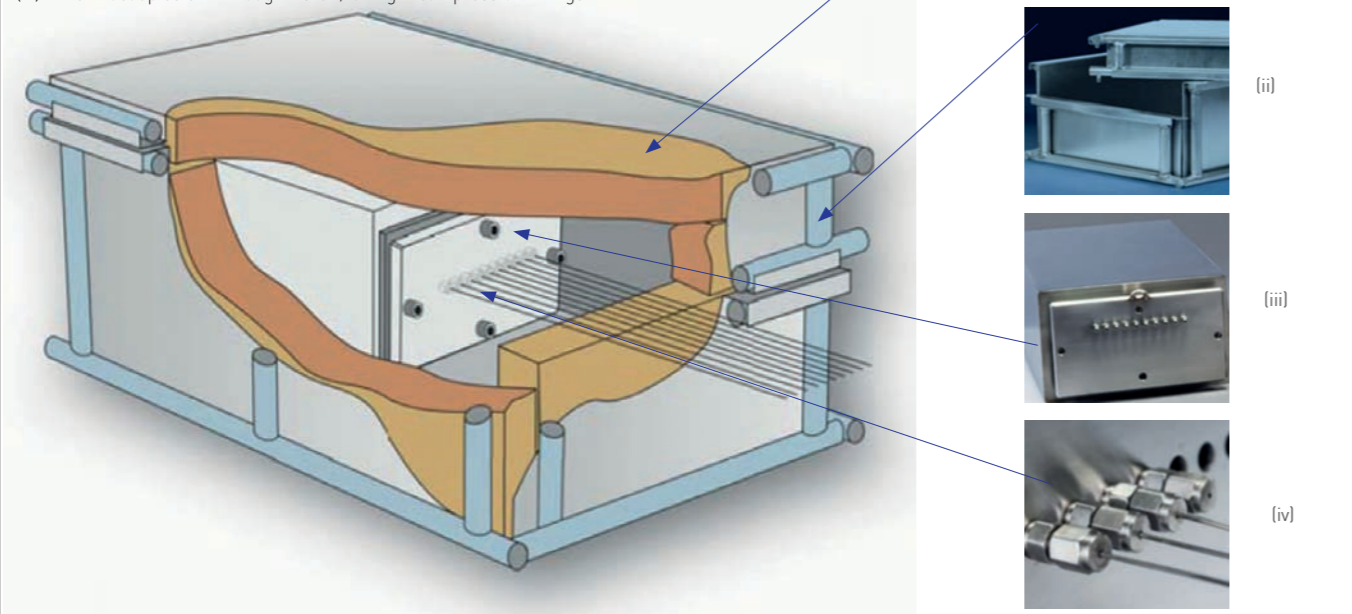


Figure 5. Schematic of RF Telemetry Real Time Monitoring Network

connection for short range localised download and reset (direct from within the barrier) the logger memory of 3.8M allows even the longest processes to be measured with highest resolution to deliver the detail you need. An optional unique 2-way telemetry package offers live real time logger control and process monitoring with the benefits detailed in a later section.

Innovative Thermal Barrier Design

The Carburizing process by its nature is very demanding when considering protection of the datalogger from high temperatures and rapid temperature and pressure changes experienced in either the gas or oil quench. Unique innovative barrier solutions have been developed for such applications by PhoenixTM.

Low Pressure Carburizing (LPC) with High Pressure Gas Quench – the Design Challenge

A range of thermal barriers are available to cover the different carburizing process specifications. As shown in **Figure 3** the performance needs to be matched to temperature, pressure and obviously space limitations in the LPC chamber.

The barrier design is made to allow robust operation run after run where conditions are demanding in terms of material warpage. Some of the key design features are listed in **Figure 3a**.

LPC or Continuous Carburizing with Oil Quench – the Design challenge

Although commonly used in Carburizing,

oil quenches have historically been impossible to monitor. In most situations monitoring equipment has been forced to be removed from the process between carburizing and quenching steps to prevent equipment damage and potential process safety issues. As the quench is a critical part of the complete carburizing

process many companies have longed for a means by which they can monitor and control their oil quench hardening process. Such information is critical to avoid part distortion and allow full optimisation of hardening operation.

When designing a quench system (Thermal Barrier) the following important considerations need to be taken into account.

- Data logger must be safe working temperature and dry (oil free) throughout process.
- Internal pressure of sealed system needs to be minimised.
- Complexity of operation, and any distortion needs to be minimized.
- Cost per trial has to be realistic to make it a viable proposition.

To address the challenges of the oil quench PhoenixTM developed a radical new barrier design concept summarised in **Figure 4**. This design has successfully been applied to many different oil quench processes providing protection through the complete carburizing furnace, oil quench and part wash cycles.

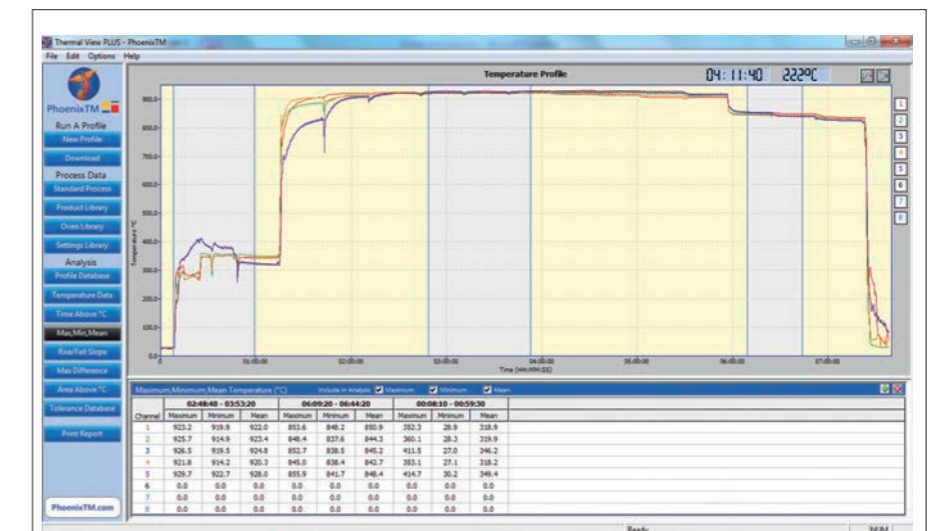


Figure 6. Thermal View SW Displaying the Temperature Profile from a Carburizing with Gas Quench Process

- Max / Min: Check maximum and minimum product temperature over whole product or product basket through phases of process carburizing, diffusion and quench.
- Time @Temp: Confirm that the soak time above required carburizing temperature is sufficient for correct carbon diffusion and surface properties.
- Temperature Slopes: Measure the quench rate of the product to ensure that the hardening process is performed correctly.

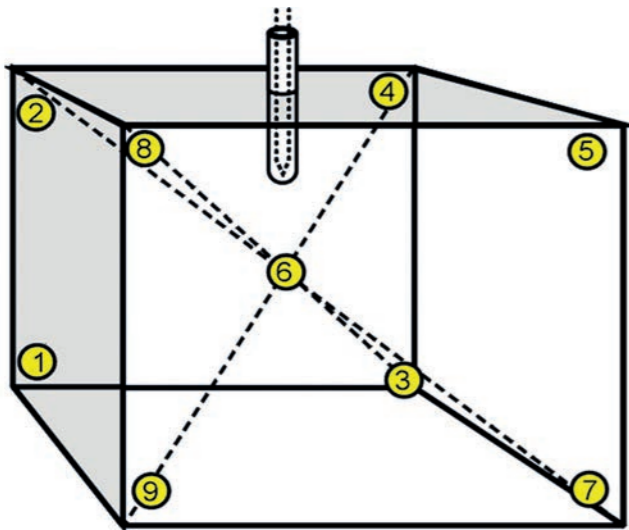


Figure 7. Typical TUS thermocouple Positions – 9 Point Survey. Furnace void corners and center.

Live Radio Communication

The logger is available with a unique 2-way RF system option allowing live monitoring of temperatures as the system travels through the carburizing processes. Furthermore, if necessary using the RF system it is possible to communicate with the logger, installed in the barrier, to reset/download at any point pre, during and post-run.

Provided with a high performance ‘Lwmesh’ networking protocol the RF signal can be transmitted through a series of routers linked back to the main coordinator connected to the monitoring PC. The routers are located at convenient points in the process, positioned to maximise signal reception. Being wirelessly connected they eliminate the inconvenience of routing communication cables or providing external power as needed on other commercial RF systems.

In many processes there will be locations where it is physically impossible to transmit a strong RF signal. In carburizing obviously within the oil quench, the RF signal is not capable of escaping when the system is submerged. With conventional systems this results in process data gaps. For the PhoenixTM system this is prevented using a unique fully automatic ‘catch up’ feature. Any data that is missed will be sent when the RF signal is re-established post quench guaranteeing in most applications 100% thru-process data review.

Thru-Process Data Analysis and Temperature Uniformity Surveys (TUS)

In thru-process temperature monitoring the data logger collects raw process data direct from the product or furnace as it follows the standard production flow. To understand the data to allow process control and optimisation a Thermal View software analysis package is used.

Using a range of analysis tools, the engineer can interpret the raw data. Key analysis calculations can be performed such as in **Figure 6**.

AMS2750E and CQI-9 Temperature Uniformity Surveys

A significant challenge for many heat treaters is the need to provide products certified to either AMS2750 (Aerospace) or CQI-9 (Automotive). To achieve this accreditation Furnace Temperature Uniformity Surveys (TUS) must be

performed at regular intervals to prove that the furnace set-point temperatures are both accurate and stable over the working volume of the furnace. Historically the furnace survey has been performed with great difficulty trailing thermocouples into the heat zone. Although possible in a batch process when considering a semi batch or continuous process this is a significant technical challenge with considerable compromises as summarised below (**Figure 7**):

Trailing Thermocouple TUS Process Steps

- TUS often carried out using long or ‘trailing’ thermocouples that exit through furnace door
- Furnace often needs to be cooled, then de-gassed so TUS frame can be set up in furnace
- Thermocouples then led out through furnace door & connected to data logger or chart recorder
- Furnace then heated to surveying temperatures
- Survey then carried out, after which furnace cooled, and thermocouples removed

Disadvantages of Traditional TUS Process

- Lots of furnace downtime may be involved (can be up to 24 hours)
- Thermocouples have to exit the furnace door
 - This may involve ‘wedging’ the door up, or ‘grooving’ out the hearth to get thermocouples out
 - Or thermocouples may get caught in furnace door
- Significant technician’s time taken up preparing report

Applying the ‘Thru-Process’ approach to TUS the measurement system is transferred into the furnace with the survey frame allowing the setup process to be done quickly, safely and repeatably. (See **Figure 8**)

Operating the System with RF Telemetry TUS data is transferred direct from the furnace back to the monitoring

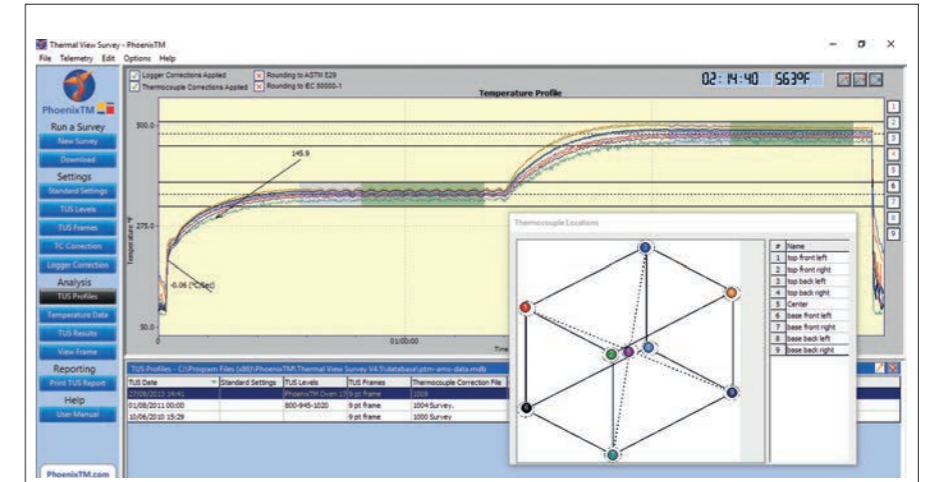


Figure 9. PhoenixTM Thermal View Survey Software showing a TUS Profile at two set survey temperatures. The Probe map shows exactly where each probe is located and easy trace identification. Detailed TUS report generated with efficiency.

PC where at each survey level, temperature stabilization and temperature overshoot can be monitored live, with TC and logger correction factors applied. The Thermal View Survey Software is developed to ensure that the final TUS report complies fully to the AMS2750E /CQI-9 standards (**Figure 9**).

Features incorporated into the Thermal View Software to provide full TUS capability include the following;

TUS Level Library - Set-up TUS level templates for quick efficient survey level specification (Survey Temp °F, Tolerance °F, Stabilization and Survey Times)

TUS Frames Library - Show clearly exact TUS Frame construction and probe location using Frame Library Templates - Frame Center and 8 Vertices.

Logger Correction File - Create a logger correction file to compensate TUS readings automatically from the logger’s internal calibration file.

Thermocouple Correction File - Create the thermocouple correction file and use to compensate TUS readings directly.

TUS Result Table & Graph View - For each TUS Temperature level see from the graph or TUS table instantaneously full survey results.

Furnace Class Reporting - Report the specified Furnace Class at each Temperature level.

Overview

The PhoenixTM Temperature Profiling System provides a versatile solution for both performing Product Temperature Profiling and Furnace TUS in industrial Heat Treatment.

Designed specifically for the technical challenges of Low Pressure Carburizing (LPC) whether implementing either high Pressure Gas Quench or Oil Quench methodology. Providing the means to **Understand, Control, Optimize and Certify** the LPC Furnace and guarantee product quality and process operation efficiency and certification.

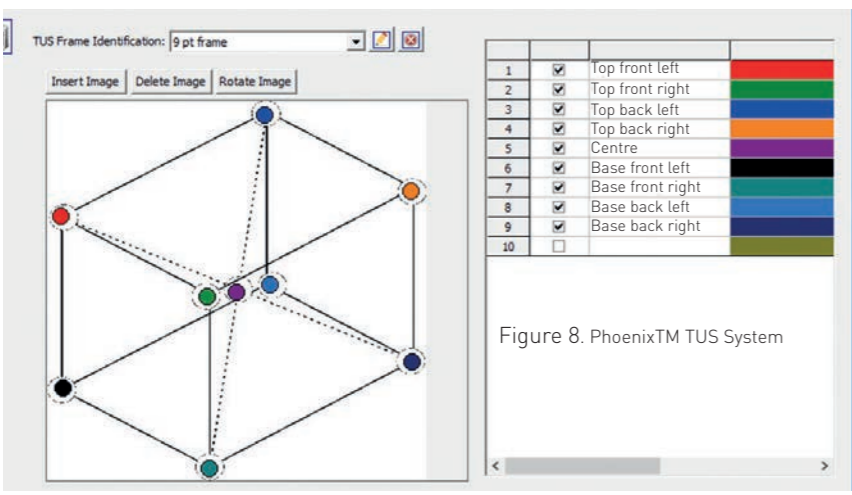
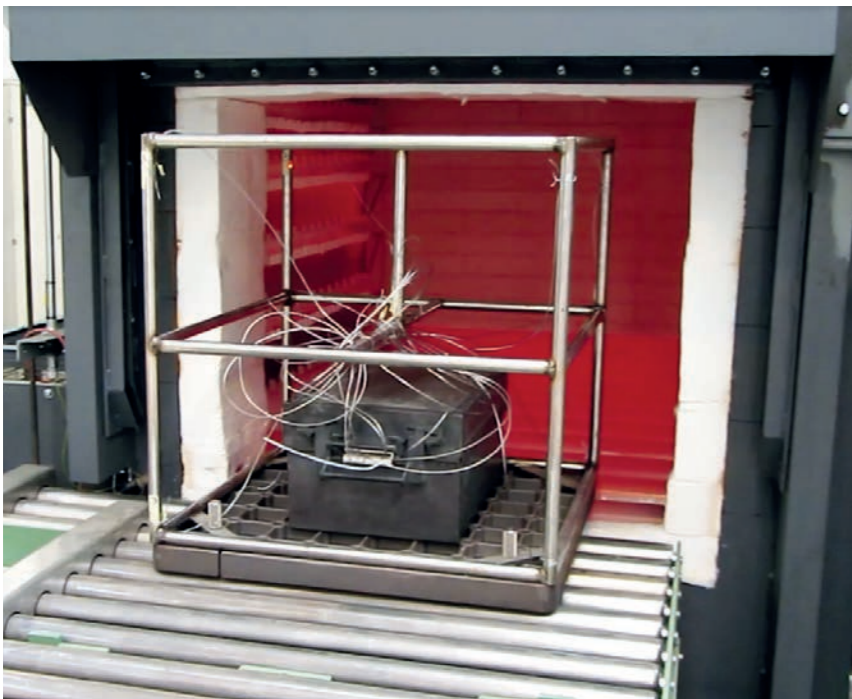


Figure 8. PhoenixTM TUS System