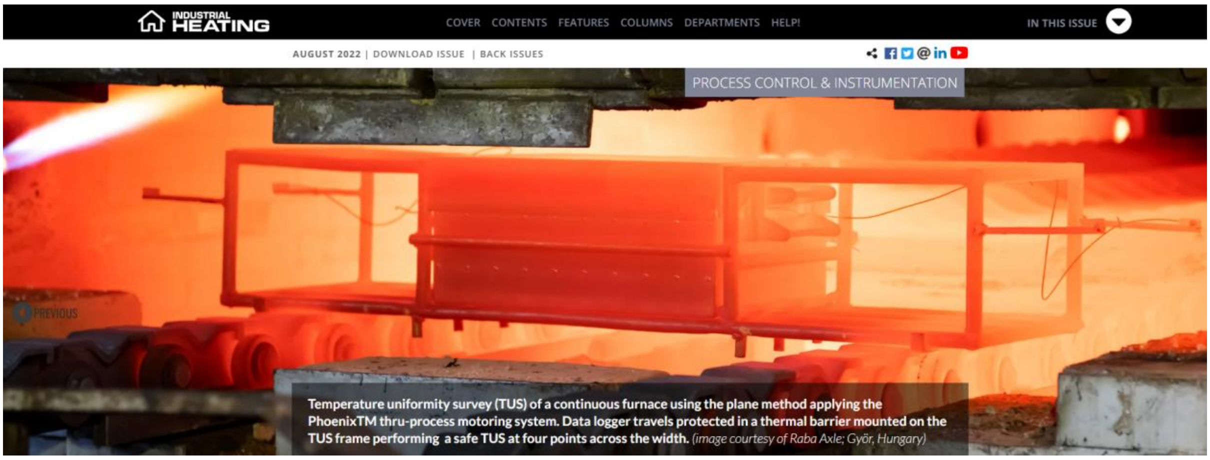

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Temperature uniformity survey (TUS) of a continuous furnace using the plane method applying the PhoenixTM thru-process motoring system. Data logger travels protected in a thermal barrier mounted on the TUS frame performing a safe TUS at four points across the width. *(image courtesy of Raba Axle; Györ, Hungary)*

PROCESS CONTROL & INSTRUMENTATION

Applying Through-Process Temperature Monitoring in Continuous Furnaces

Meeting the Challenges of AMS2750G

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Careful preparation and planning as to how pyrometry requirements should be implemented are essential from a practical perspective, especially for ever-increasing automated and complex multistage, semi-continuous or continuous processes.

In today's heat-treatment industry, we are faced daily with the challenges of complying with the regulatory standards that are relevant to our specific markets and products. Whether manufacturing automotive parts governed by CQI-9 or aerospace parts (AMS2750G, Nadcap, AC7102/8), pyrometry requirements are accepted as being demanding and requiring careful interpretation and implementation. As we all know, the devil is in the details.

This article will discuss the challenges of performing the temperature uniformity survey (TUS) with particular reference to employing the "thru-process" TUS principle applied to continuous and/or semi-continuous processes. The focus will be on the AMS2750G specification, but similar principles apply to CQI-9 with minor specification adaptations.

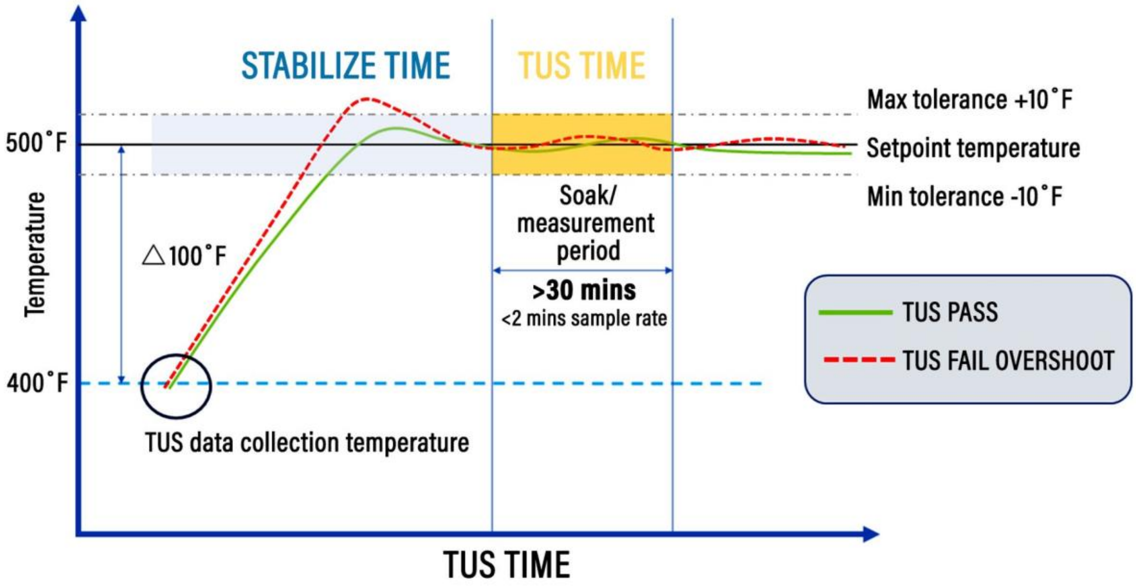


Fig. 1. Schematic of typical TUS result using hypothetical AMS2750G parameters. The green trace is a pass, while the red trace is a fail due to overshoot.

TUS Requirements Summary

A major challenge with any standard is fully understanding the meaning or definition of terms and language used. In the AMS2750G specification, TUS is defined as "a test or series of tests where calibrated field test instrumentation and sensors are used to measure temperature variation within the qualified furnace work zone prior to and after thermal stabilization." This definition itself contains important terms that we will investigate and discuss later as they apply to continuous furnaces. A schematic of the basic TUS principle is shown in Fig. 1.

TUS tolerances (±X°F) needed are defined in AMS2750G from furnace Class perspective (AMS2750G Table 16/17). However, take into account the reference to "prior to and after stabilization." Overshoot failure due to thermal inertia effects will override any successful result in the TUS minimum soak period, as shown in Fig. 1 (see the red trace line). As defined in AMS2750G, if overshoot occurs above the upper tolerance level in either approach or TUS soak, a failure will be generated. It is important that the approach is clearly defined by TUS data collection requirements (AMS2750G 3.5.10) as when all TUS and furnace sensors are no less than 100°F (55°C) below each survey temperature.

An initial survey is performed on a furnace installation or after modifications and repairs (AMS2750G 3.5.4). The initial survey temperatures shall be the minimum and maximum temperatures of the furnace's qualified operating temperature range(s). Please note, however, that intermediate TUS levels are required so that no two adjacent survey temperatures are greater than 600°F (315°C) apart.

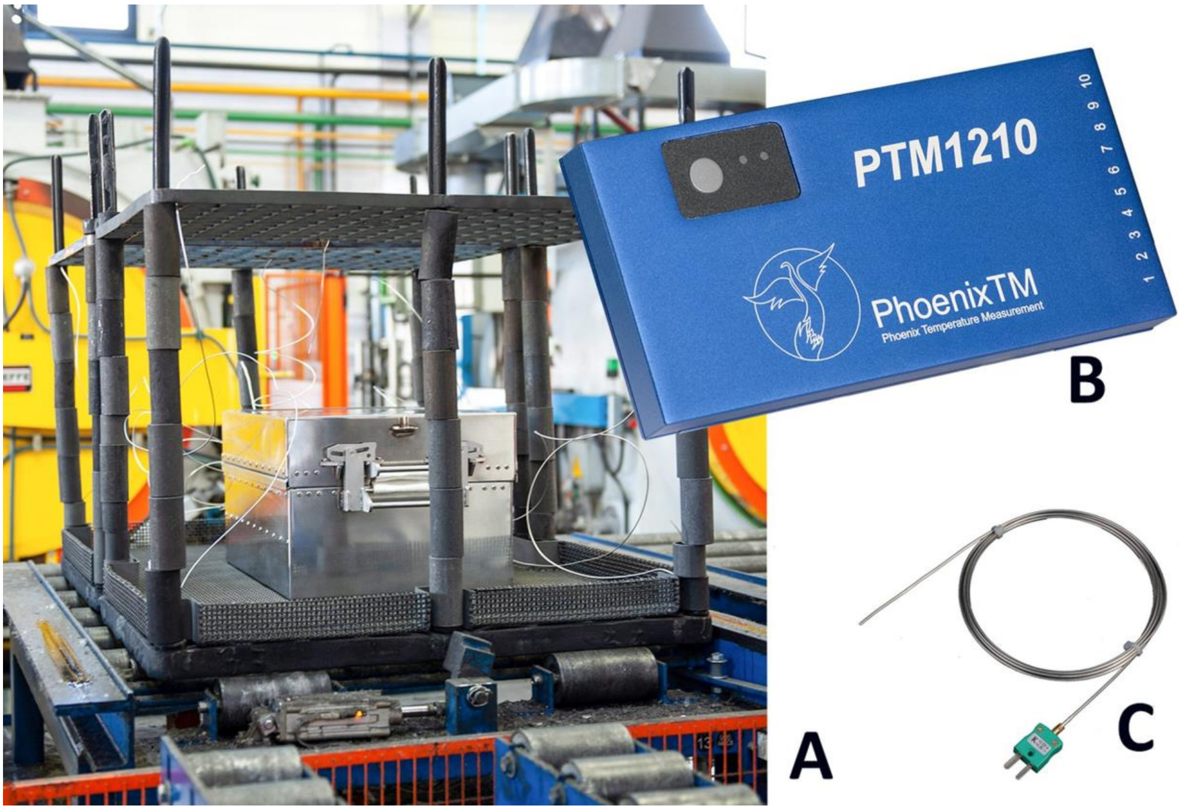


Fig. 2. The PhoenixTM thru-process TUS system is installed in a TUS frame, allowing independent travel through the furnace. The thermal barrier (A) protects the internal multi-channel data logger (B). Short, nonexpendable mineral-insulated thermocouples (C) measure temperature over the qualified work zone.

Periodic TUSs (normal and extended) are performed for single operating ranges greater than 600°F (315°C). In this case, the temperatures that are selected must be 300°F (149°C) from the minimum and 300°F (149°C) from the maximum qualified operating range determined from the initial TUS. Again, intermediate TUS levels may be required such that no two adjacent survey temperatures are greater than 600°F (315°C) apart. The TUS frequency is clearly defined for furnace classes in AMS2750G (Tables 16 and 17).

Going back to our initial definition, we now need to address the term "qualified furnace work zone." It is important to differentiate this from the furnace dimensions and even the control zone. The definition provided by AMS2750G 2.2.48 states: "The portion of a thermal processing equipment volume where temperature variation conforms to the required uniformity tolerance within the qualified operating temperature range as defined by the placement of sensors during the most recent temperature uniformity survey."

From a simplistic and practical perspective, the need is for placement of temperature sensors over a defined volume, reflected by the process, to prove uniformity of heating within that volume against specification requirements. The accurate and reproducible placement of such sensors is critical to the success of the initial and subsequent periodic TUS runs.

Thru-Process TUS Solution for Continuous Furnace Process

Traditionally, TUSs are performed on a static batch furnace by using a field test instrument (a chart recorder or static data logger) external to the furnace with thermocouples trailing into the furnace heating chamber.

Trailing thermocouples have limitations, especially when the product transfer is continuous. The trailing thermocouple method is often labor-intensive, potentially unsafe and can create compromises to the TUS data collected. The choice of thermocouple type may well be limited to an expendable (AMS2750G 2.1.21, Table 3) exposed-junction thermocouple type, which requires the flexibility of glass braid/ceramic fiber exposed junction to allow transfer of long lengths into and through the furnace with a compromise of durability and limited reuse (AMS2750G Table 5). The insulation is obviously prone to damage from snagging in the furnace, which would restrict use further as defined by AMS2750G section 3.1.6. Inspection and testing of thermocouples to avoid failed TUS runs is critical but time-consuming.

For semi-continuous (pusher) or continuous (belt) furnaces, the thru-process TUS principle overcomes the problems of trailing thermocouples. A multi-channel data logger travels into and through the heat-treat process protected by a thermal barrier. Thermal-barrier design and specification are customized to suit the process being monitored (time/temperature/pressure, etc.).

Requiring only short thermocouple lengths contained within the TUS frame, nonexpendable (AMS2750G 2.2.36, Table 3) thermocouples can be employed with ease. Robust mineral-insulated thermocouples, typically type K or N, can be permanently fixed to the TUS frame. This both reduces setup time and guarantees that thermocouple positions are consistent for periodic TUS work as defined by AMS2750G 3.1.7. Temperature data is then transmitted live to a monitoring PC running TUS analysis software via a two-way RF telemetry link direct from the furnace.

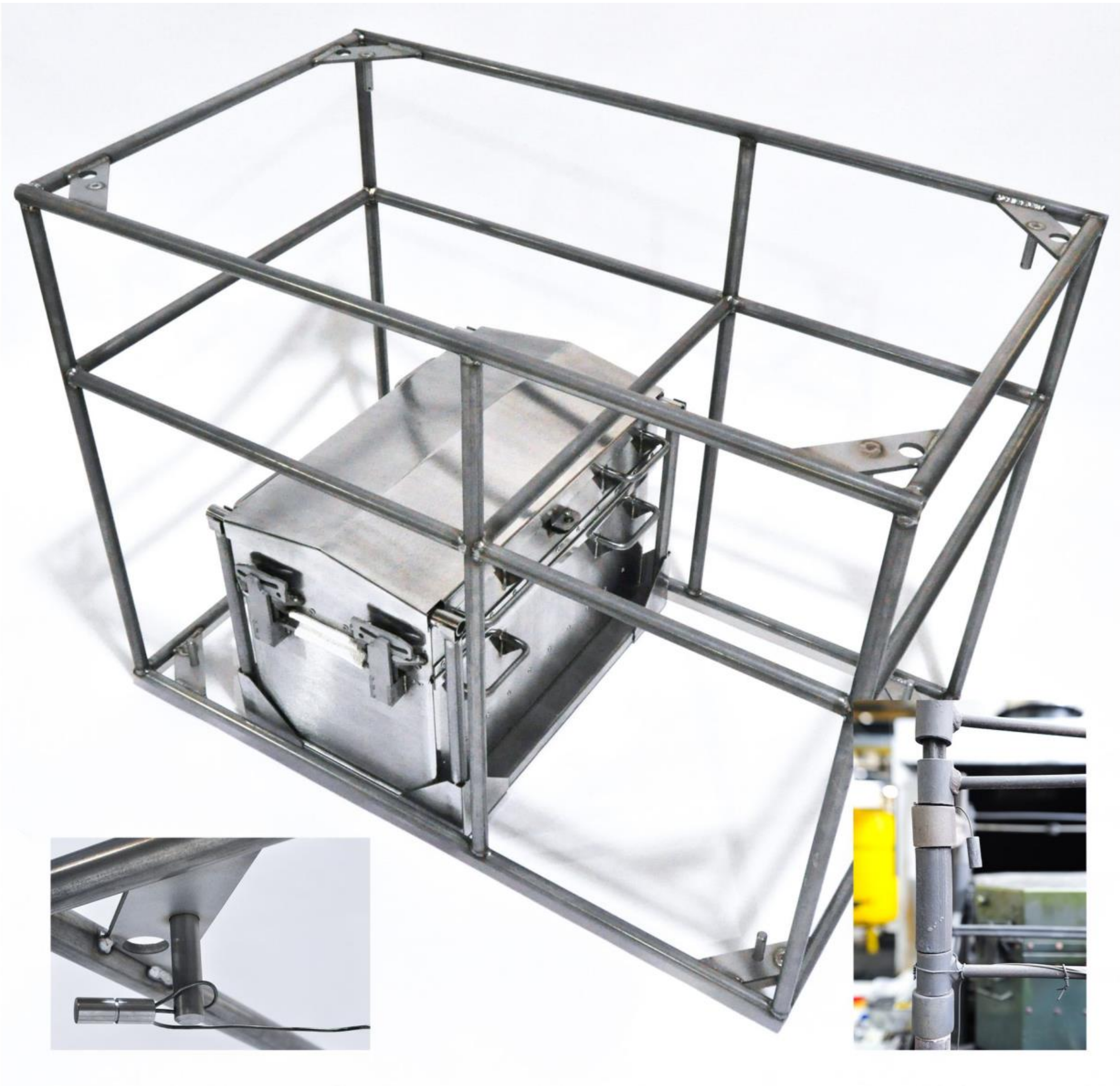


Fig. 3. This PhoenixTM thru-process TUS system is installed in a volumetric TUS frame. Thermocouples are mounted on fixed mounts at the eight vertices of the frame and center point as shown with heat sink fixed to the sensor hot junction.

Volumetric Method (AMS2750G 3.5.11.6)

For semi-continuous furnaces where there may be multiple independent control zones, the volumetric method is employed. A three-dimensional TUS frame (Fig. 3) is transferred to each sequential qualified work zone. It may be necessary to perform multiple surveys to cover the entire work zone.

TUS sensors are located in three dimensions to represent a portion (basket or tray) or the entire qualified work-zone volume. The number of thermocouples and positions on the TUS frame are, for a batch TUS (AMS2750G Figure 1 and Tables 17 and 18), based on the volume of the TUS basket or tray(s) used.

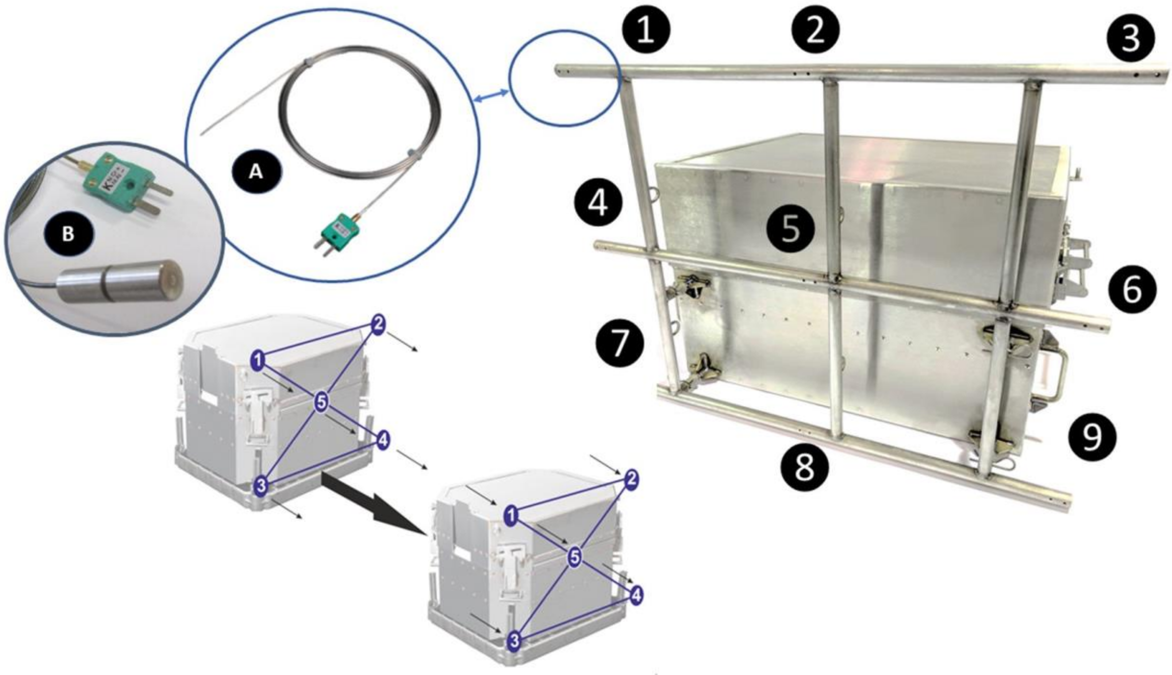


Fig. 4. The PhoenixTM thru-process TUS system shows a TUS frame for use applying the plane method. Thermocouples are installed at nine locations either with (A) an exposed hot junction or (B) a heat sink.

Plane Method (AMS2750G 3.5.11.7)

For continuous conveyorized (belt) furnaces, it is recommended that an alternative thermocouple test rig is employed, which is called the plane method. Since the system travels through the furnace, it is only necessary to monitor the temperature uniformity over a two-dimensional plane/slice of the furnace (Fig. 4).

All parameters used during the TUS shall reflect the normal operation of the equipment used during production, as detailed in AMS2750G 3.5.6. The initial TUS shall be performed at the minimum and maximum temperatures of the qualified operating temperature range(s) at the highest and lowest traverse speeds used during production. The periodic TUS may be performed at any traverse speed used during production if at least one TUS per year includes highest and lowest traverse speeds (AMS2750G 3.5.11.5).

The number and location of thermocouples required in the plane method is determined by the work-zone height and width as defined in AMS2750G Table 19 and as detailed in Table 1.

Temperature readings from all TUS sensors shall be recorded at least every two minutes, with a minimum of 10 sets of readings recorded for each qualified work zone. The traverse may be repeated as many times as necessary to ensure that any recurrent temperature pattern is identified at all locations through each qualified work zone.

For TUS monitoring, it is acceptable to use either exposed-junction thermocouples or thermocouples fitted with a heat sink (AMS2750G 2.2.27). The heat-sink (Figs. 3 and 4) diameter should not be >0.5 inch and should not exceed the thickness of the thinnest material being processed. The material should have a room-temperature thermal conductivity consistent with heat-treat material.

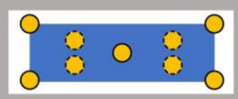
Qualified Work Zone Height	Qualified Work Zone Cross Section	Minimum Number of TUS Sensors	Location of TUS Sensors	Schematic – Sensor Location on Frame
< 1 Foot	Circular section: Radius < 3 inches Rectangular section: Width and height < 6 inches	1	TUS sensor at center	
	Other furnaces with qualified work zone < 1 foot high	3 Additional each 2 feet of width over 8 feet	2 TUS sensor locations at opposite sides of qualified work zone mid height. 1 TUS sensor at center. Remaining sensors symmetrically distributed about center in the plane.	
>1 Foot	< 8 ft^2	5	4 TUS sensor locations at corners of qualified work zone. One at center. Remaining sensors symmetrically distributed about center in the plane.	
	> 8 ft^2 & < 16 ft^2	7		
	> 16 ft^2	9		

Table 1. Number and locations of TUS sensors for continuous and semi-continuous furnaces using the plane method (AMS2750G Table 19)

Thermocouple setup needs to be consistent for initial and subsequent periodic TUS runs, which is achieved via the use of permanently rigged TUS frames (Figs. 3 and 4).

For continuous TUS operations, the traverse speed monitoring and recording is important because it is used to calculate the qualified work-zone length (AMS2750G 3.5.11.9). Each qualified work-zone length is the sum of the elapsed time during which the TUS sensors were within the required TUS tolerance at the traverse speed used.

In most TUS situations (sensors <10), no TUS sensor failures are accepted. Some limited failures are permitted (AMS2750G Tables 20 and 21) above 10, but it is important to note that no failures are accepted for corner sensors.

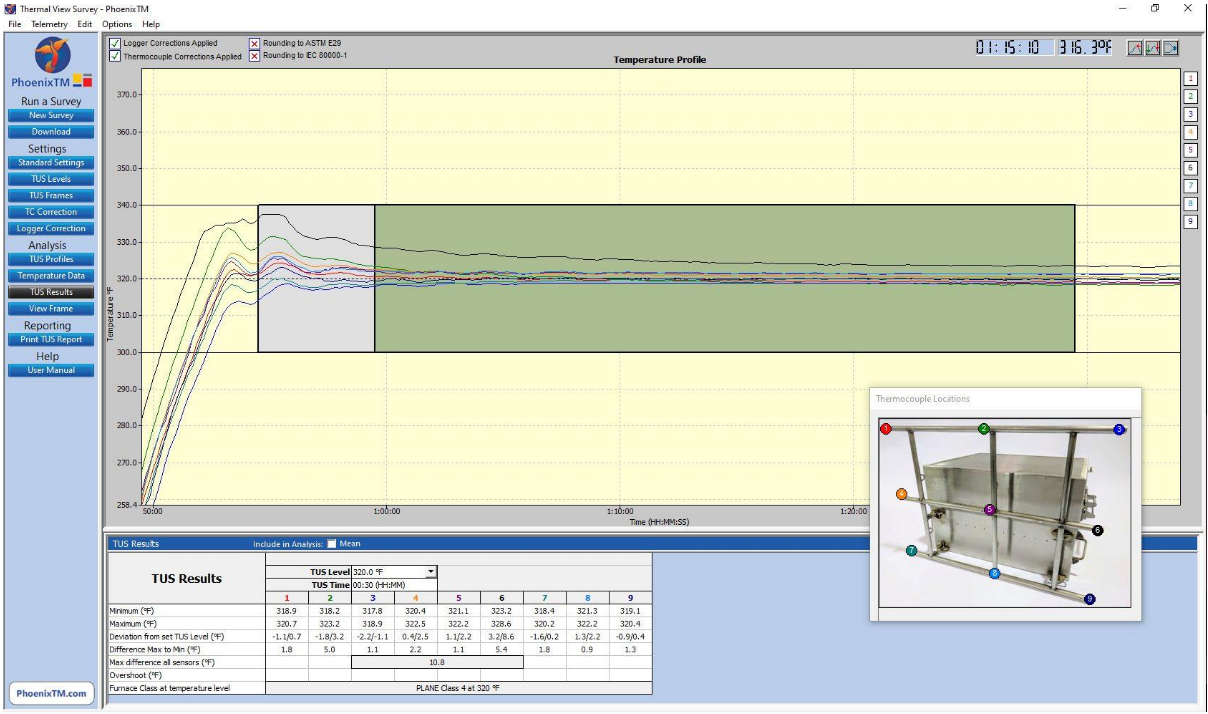


Fig. 5. PhoenixTM Thermal View Survey software shows the visual and data analysis of a specific TUS level using the plane method applied to a continuous belt furnace.

TUS Analysis and Reporting

Collecting TUS data from the process is only part of the procedure. The data needs to be reviewed, analyzed and reported to meet Pass and Fail criteria (AMS2750G 3.5.14) and report content (AMS2750G 3.5.16). This can be done manually, but it is complicated and both time- and labor-intensive.

Commercial software packages, such as the PhoenixTM Thermal View Survey, provide an automated alternative processing of the RF telemetry data sent from the TUS data logger. Using customized TUS template files – including TUS levels, furnace class, TUS frame, thermocouple and data-logger correction factors – the analysis of each TUS level can be performed accurately and efficiently for each TUS run. A report template allows comprehensive yet clear reporting of all test criteria and parameters. TUS reports can be quickly generated, stored and shared in hard copy or digital formats.

Overview

The PhoenixTM "thru-process" system provides a versatile solution for performing furnace-surveying TUS with particular value to monitoring semi-continuous or continuous heat-treatment processes to satisfy AMS270G or CQI-9 specifications. It also provides the means to understand, control, optimize and certify your heat-treatment process.

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