Meeting Temperature Uniformity Surveying challenges of Furnaces to AMS2750

Dr Steve Offley "Dr O"*

In today's heat treatment industry, we all face the daily challenge of complying to regulatory standards, relevant to our specific markets and products. Whether manufacturing automotive parts governed by CQI-9 or aerospace parts AMS2750H (Issued 07/24 NADCAP AC7102/8), pyrometry requirements are accepted as being demanding and require careful interpretation and implementation. As we all know "the devil is in the detail." Careful preparation and planning as to how pyrometry requirements should be implemented is essential from a practical perspective, especially for ever increasing automated, complex multi-stage, semi-continuous or continuous heat treatment processes.

The following 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. A focus will be made on the AMS2750H specification, but similar principles apply to CQI-9 with minor specification adaptations.

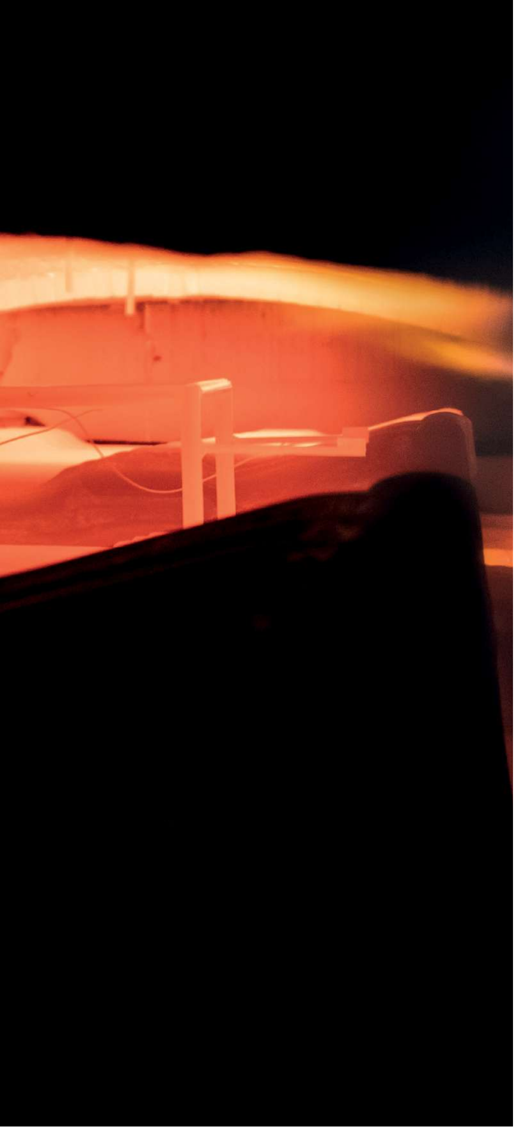
Temperature Uniformity Survey (TUS) – Requirements Summary

A major challenge with any standard is fully understanding the meaning or definition of the terms and language used. In the AMS2750H 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 stabilisation."

This definition itself contains important terms which we will investigate and discuss later as they apply to continuous furnaces. A schematic of the basic TUS principle is shown in **Figure 1**.

TUS tolerances (± X°C) needed are defined in AMS2750H from a furnace Class perspective (AMS2750H Table 8, 15 & 16). Returning to the TUS definition, care must be taken when contemplating the meaning behind: 'Prior to and after Stabilisation.' Overshoot failure due to thermal inertia effects, as shown in **Figure 1** (Red Trace), will override any successful result in the TUS minimum soak period. As defined in AMS2750H, if an overshoot occurs above the upper tolerance level

*Product Marketing Manager, PhoenixTM



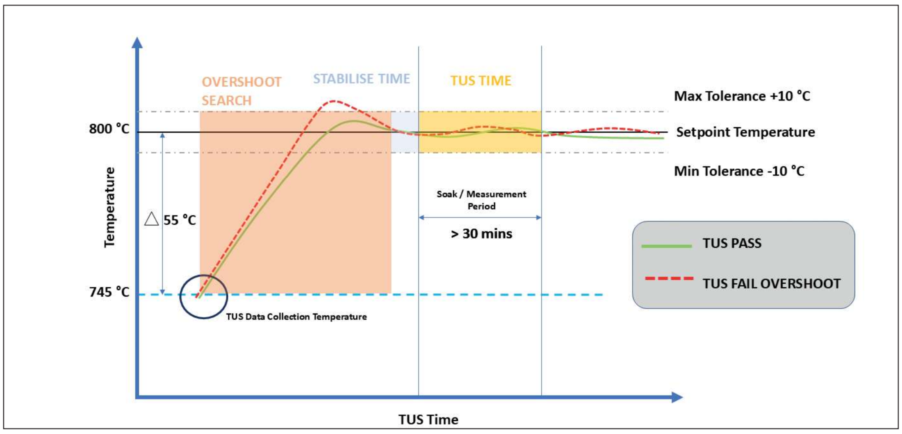


Figure 1: Schematic of typical TUS result using hypothetical AMS270H parameters. Green Trace (PASS) Red Trace (FAIL) due to overshoot.

in either approach or TUS soak, a Fail will be generated. It is important that the approach is clearly defined by TUS minimum data collection requirements (AMS2750H 3.5.10) when all TUS and furnace sensors are no less than 55 °C below each target survey temperature.

An initial survey is performed at furnace installation, or after modifications and repairs (AMS2750H 3.5.4). The Initial survey temperatures shall be the minimum and maximum temperatures of the furnaces qualified operating temperature range(s). Note, however, that intermediate TUS levels are required so that no two adjacent survey temperatures are greater than 335 °C apart.

Periodic TUS's are performed at a frequency clearly defined for the furnace class by Tables 16 & 17. For single operating temperature ranges greater than 335 °C, during each periodic TUS, temperatures shall be selected so that one temperature is within 170 °C of the maximum and another temperature is within 170 °C of the minimum qualified operating temperature range(s), there must also be no more than 335°C increments in-between adjacent TUS temperatures.

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 control zone. The definition provided (AMS2750H 2.2.48) is: "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 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.

TUS Solutions for Batch & Continuous Furnace Processes

Traditionally Temperature Uniformity Surveys (TUS) are performed using a field test instrument (chart recorder or static data logger), external to the furnace, with thermocouples trailing into the furnace heating chamber **Figure 2**.

Trailing thermocouples have limitations, especially when the product transfer is continuous. The trailing thermocouples method is often labour intensive, potentially unsafe and can create compromises to the TUS data being collected.

For a semi-continuous (pusher) or continuous (belt) furnaces, the 'Thru-process' TUS principle overcomes the problems of trailing thermocouples. A multi-channel Data Logger (field test instrument) travels into and through the heat treat process protected by a Thermal Barrier. Thermal Barrier design and specification is customised to suit the process being monitored (Time/Temperature/Pressure etc). Available with an RF Telemetery option, the TUS temperature data can be transmitted directly from the furnace to an external monitoring PC during the survey. Running Survey software the live data can then be visually checked to be within toleranace. Following data collection the TUS can be fully analysed and reported, complying fully to AMS2750H or CQI9, with efficiency and confidence. **Figure 3**.

Figure 2. Typical TUS survey set-up for a static batch furnace. PhoenixTM PTM1-420 External data logger connected directly to a nine point TUS frame used to measures the temperature uniformity over the volumetric working volume of the furnace.

Figure 3: PhoenixTM 'Thru-process' TUS system installed in TUS Frame allowing independent travel through the furnace. The Thermal Barrier (1) protects internal multi-channel Data Logger (2) "Field Test Instrument". Short nonexpendable mineral insulated thermocouples (3) measure temperature over the qualified work zone. TUS data transmitted from furnace to monitoring PC via RF Telemetry (4) where analysis and reporting can be performed to AMS2750H with Thermal View Survey Software (5).

TUS Thermocouple Choices and Restrictions

The choice of thermocouple type used for the TUS is significantly influenced by whether trailing thermocouples or thru-process monitoring is applied. For batch or continuous furnaces the choice of trailing thermocouples may be limited to an expendable (AMS2750H 2.2.21, **Table 3**) exposed junction thermocouple type, requiring the flexibility of glass braid / ceramic fibre exposed juction to allow transfer of long lengths into or through the furnace. The use of such expendable sensors compromises durability and limits reuse (AMS2750H **Table 5**). The insulation is obviously prone to damage from snagging in the furnace which would restrict use further as defined by AMS2750H section 3.1.6. Inspection and testing of thermocouples to avoid failed TUS runs is critical, but time consuming. It is important that uses, operational life, and temperature history of the expendable thermocouple is carefully monitored and recorded. Section3.1.7 and **Table 5** in AMS2750H clearly states the strict conditions of use for different sensor types and materials which need to be adhered to.

In contrast, for Thru-Process monitoring, only short thermocouple lengths are required to connect the Data Logger within the Thermal Barrier and the TUS Frame. As such, nonexpendable (AMS2750H 2.2.36, **Table 3**) thermocouples can be employed with ease. Robust mineral insulated thermocouples (MIMS), typically type K or N, can be permanently fixed to the TUS frame. This both reduces set-up time, and guarantees that thermocouple postions are consistent for periodic TUS work as defined (AMS2750H 3.1.7 **Table 5**).

Baring physical damage the MI thermocouples can be used, unrestricted, for up to three months (Type K) and three-months (Type N) or longer if recalibration is successful, at three months anniversary. It is important as for expendable thermocouples that uses, opertational life and temperture history of the non-expendable thermocouple is carefully monitored and recorded to complement the pyrometry work and reporting requirements.

TUS Measurement Accuracy – Data Logger and Thermocouple Correction

Working to AMS2750H the accuracy of the temperature measurement is strictly controlled. Data Loggers and thermocouples provided by PhoenixTM comply fully with accuracy and calibration criteria as defined in **Table 1** and **Table 7** and give full 0.1 °C / 0.1 °F measurement resolution as required (AMS2750H 3.2.2.2). The field test instrument "data logger" needs to have a calibration accuracy of ±0.6 °C or ±0.1% of temperature reading, whichever is greater. Base metal thermocouples need to have a calibration accuracy ±1.1 °C or ±0.4%* (*Percent of reading or correction factor °C, whichever is greater).

Figure 4. TUS thermocouple Definitions

4.1 (left) Expendable Thermocouple - Sensors where any portion of the thermoelements are exposed to the thermal process equipment environment. Glass Fibre exposed junction thermocouple.

4.2 (right) Non-expendable Thermocouple - Sensors having no portion of the thermoelements exposed to the thermal process equipment environment. Mineral insulated metal sheathed (MIMS).

Figure 5: PhoenixTM Thru-process TUS system installed in Volumetric TUS Frame. Thermocouples mounted on fixed mounts at the eight vertices of the frame and centre point as shown with heat sink fixed to sensor hot junction.

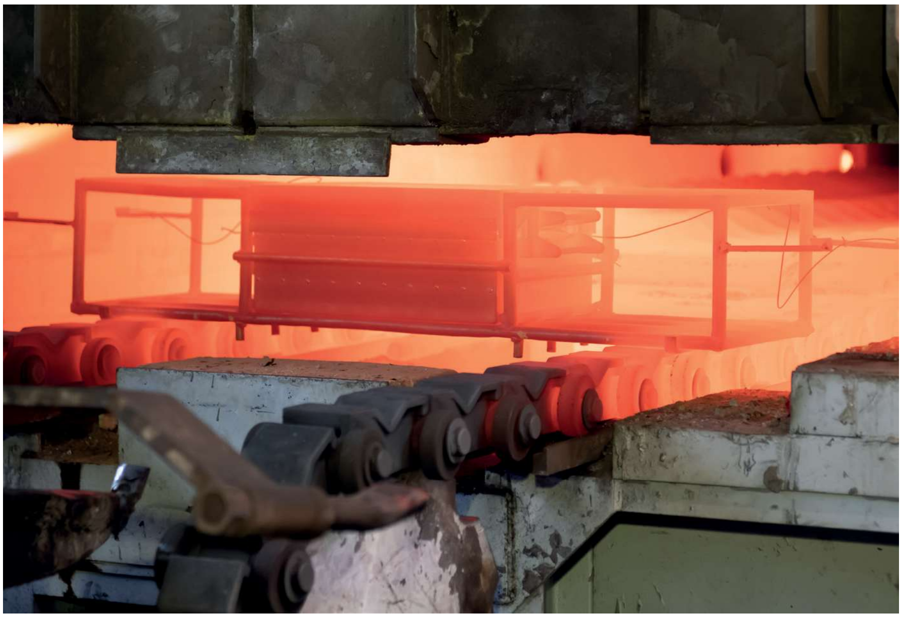


Figure 6: Temperature Uniformity Survey (TUS) of a continuous furnace using the plane method applying the PhoenixTM thru-process motoring system. Data logger travels protected in a thermal barrier mounted on the TUS frame performing a safe TUS at 5 points across the width, impossible by trailing thermocouples. (Photograph courtesy of Raba Axle, Györ, Hungary).

To maximise measurement accuracy the PhoenixTM system provides both Data Logger and thermocouple correction factors to be applied automatically to the raw TUS data. The Data Logger correction factors can be read directly from the on-board digital Data Logger calibration file. For both Data Logger and thermocouples correction factors are interpolated across the complete calibration range using the linear method as permitted (AMS2750H 3.1.4.8). This approach means that the accuracy of entire TUS data set is guaranteed compared with applying a single correction factor calculated at a single nominated temperature which may not truly reflect the complete temperature range.

Volumetric Method (AMS2750H 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 (**Figure 5**) 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, e.g. basket, tray, or the entire qualified work zone volume. The number of thermocouples and positions on the TUS Frame are, as for a batch TUS (AMS2750H **Figure 1** and **Tables 17** and 18), based on the volume of the TUS basket or tray(s) used.

Plane Method (AMS2750H 3.5.11.7)

For continuous conveyorised (belt) furnaces it is recommended that an alternative thermocouple test rig is employed 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 (**Figure 6**).

All parameters used during the TUS shall reflect the normal operation of the equipment used during production as detailed in AMS2750H 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 annum includes highest and lowest traverse speeds (AMS2750H 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 AMS2750H **Table 19** as detailed below **Table 1**. Temperature readings from all TUS sensors shall be recorded at least every 2 minutes, with a minimum of ten 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 thermocou-

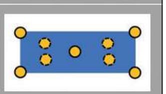
Qualified Work Zone Height	Qualified Work Zone Cross Section	Minimum Number of TUS Sensors	Location of TUS Sensors	Schematic – Sensor Location on frame
< 300 mm	Circular section: Radius < 76 mm Rectangular section : Width and Height < 152 mm	1	TUS sensor at center	
	Other furnaces with qualified work zone < 300 mm high	3 1 Additional each 610 mm of width over 2.4 m	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.	
> 300 mm	< 0.75 m²	5	4 TUS sensor locations at corners of qualified work zone. One at center. Remaining sensors symmetrically distributed about center in the plane.	
	> 0.75 m² & < 1.5 m²	7		
	> 1.5 m²	9		

Table 1. Number and locations of TUS sensors for continuous and semi-continuous furnaces using the plane method. (AMS2750H TABLE 19)

ples or thermocouples fitted with a heat sink (AMS2750H 2.2.27). The heat sink (**Figure 5 & 6**) diameter should not be >13 mm and not exceed the thickness of the thinnest material being processed. The material should have a room temperature thermal conductivity consistent with heat treat material.

Thermocouple set-up needs to be consistent for initial and subsequent periodic TUS runs which is achieved by using of permanently rigged TUS frames. **Table 1**

For continuous TUS operations the transverse speed monitoring and recording is important as it is used to calculate the qualified zone length (AMS2750H 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. If above 10, some limited failures are permitted (AMS2750H **Table 20/21**), but it is important to note no failures are accepted for corner sensors or adjacent sensors.

TUS Analysis and Reporting

Obviously collecting TUS data from the process is only a part of the process. The data needs to be reviewed, analysed, and reported to meet Pass and Fail criteria (AMS2750H 3.5.14) and report content (AMS2750H 3.5.16). This can be done manually but is complicated and labour intensive, possibly taking hours.

Commercial software packages such as the PhoenixTM Thermal View Survey provides an automated alternative processing of the RF telemetry data sent from the TUS data logger. Using customised TUS template files including (TUS Levels, Furnace Class, TUS Frame, Thermocouple & Data Logger Correction Factors) the analysis of each TUS level can be performed accurately and efficiently 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' Temperature Monitoring System provides a versatile solution for performing Furnace Surveying TUS with particular value to monitoring semi-continuous or continuous heat treatment process to satisfy AMS270H or CQI-9 specifications. Providing the means to fully Understand, Control, Optimise and Certify your Heat Treatment Furnace. ■

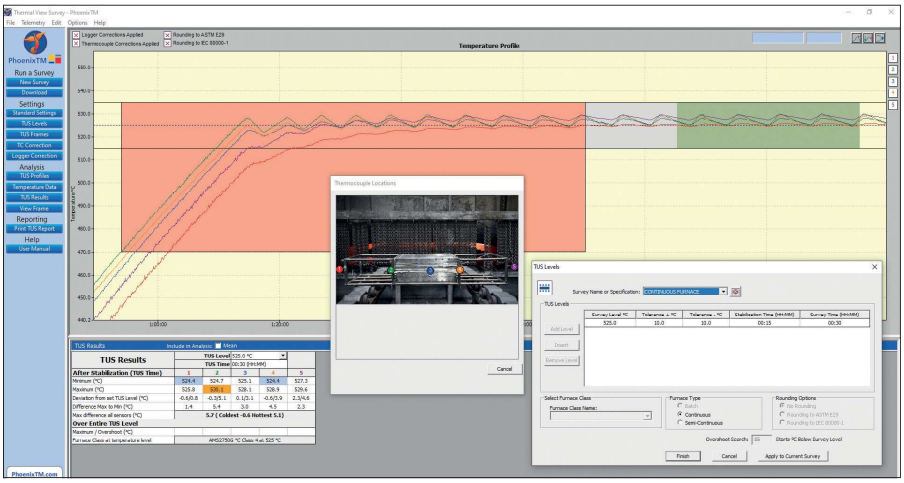


Figure 7: PhoenixTM Thermal View Survey Software showing the visual and data analysis of a specific TUS level using the plane method applied to a continuous belt furnace.

Dr Steve Offley aka "Dr O"
Product Marketing Manager
PhoenixTM Ltd
Cambridgeshire UK
E: steve.offley@phoenixtm.com

"Over 25 years' experience in the industrial furnace temperature monitoring / surveying market."
www.phoenixtm.com
Tel: 01353223100