

Figure 2.3: System post slab reheat furnace being manoeuvred to allow the safe removal of the PhoenixTM datalogger

# Thru-process temperature profiling for heat-treat efficiency

## An accurate solution to furnace mathematical model validation in slab and billet reheat

In the steel reheat market mathematical modelling is crucially applied in furnace control systems. Such models allow accurate control of transient times and drop out temperature of steel slabs or billets during the pre-rolling, reheat operation. Critical to the success of such mathematical models is the availability of accurate actual product temperature profile data, against which models can be validated or optimised.

The PhoenixTM 'thru-process' temperature profiling system has been designed specifically to allow comprehensive monitoring of the slab/billet, through the entire furnace pre-heat and soak processes. Offering up to 20 thermocouple inputs using the PhoenixTM high temperature PTM1-220-HT data logger (Figure 1) temperatures can be measured at the surface, centre and base of the product at various positions along its length.

The resulting temperature profile data (Figure 4) can be imported directly into the theoretical controller model, to validate correct selection of process parameters and assumptions applied.

Passing through the reheat furnace reaching temperatures of up to 1300°C, for up to 8 hours, the data logger requires significant thermal protection. Such protection is provided by the specially designed



Figure 1: PhoenixTM PTM1-220-HT data logger provides up to 20 measurement channels with a choice of type K or N thermocouple types with a data logger accuracy of +/- 0.3°C

TS07 thermal barrier range. Manufactured using graded insulation layers and an evaporative inner water tank, the phased evaporation of water maintains the logger temperature at a safe 100°C. The thermal barrier is placed on the slab/billet (Figure 2.2) or in circumstances where height clearance is an issue, located in a space machined out of the end of the test slab/billet. This can reduce the overall height to 325-350mm minimum, which is normally enough to pass through the entrance and exit doors of the furnace.

Support of the thermal barrier in the machined-out slab end is obviously critical. This is generally achieved by one of two ways, either on hanger bars or a plate welded to the slab. Weld plate supports fitted to the slab base may be considered risky as at high temperatures the welded joints may fail. The more robust method of hanger bars employs solid forged 25mm thick steel strip welded to the slab top face, either side of the barrier cavity (See Figure 2.2).

### Thermocouple selection and accuracy

For reheat processes typically mineral insulated (MI) thermocouples are chosen due to their robust operation above 1000°C. Generally, either Type K or Type N thermocouples are used but noble metal



Figure 2.1: A PhoenixTM profiling system showing typical thermal barrier design (thermal blanket insulated water tank) and PTM1220 data logger held in insertion tray



Figure 2.2: System pre-run installed on machined out steel blank slab showing hanger bars supporting the barrier welded to the top face of the slab

thermocouples (R & S) are also a possibility although at a higher cost. Final selection is made considering accuracy and temperature range. Type N are more stable at high temperatures and therefore have better accuracy but have an upper limit of 1300°C. Type K in comparison has an upper limit of 1370°C. Having selected the thermocouple type, the final choice is the diameter and length of the thermocouples to match the dimensions of the slab being monitored. Typically, 3mm diameter MI probes are used to reduce the risk of break down of the magnesium oxide insulation and the resulting risk of 'shunt impedance' errors.

### Increasing the diameter of the mineral insulated thermocouple can help to increase accuracy

To maximise measurement accuracy in the slab process, the PhoenixTM system offers the ability to apply both data logger and thermocouple correction factors to the temperature data automatically in the Thermal View operating software. These correction factors can be efficiently applied after creating correction factor files from the data logger (downloaded directly) and thermocouple calibration certificates.

### The optimal thermocouple diameter

Increasing the diameter of the mineral insulated thermocouple can help to increase accuracy but a balance has to be made between the highest achievable accuracy, flexibility when installing, and heat transfer back to the data logger. Commercially, mineral insulated thermocouples for slab reheat applications are available in a range of diameters: 3mm, 4.5mm and 6mm. Of these the latter, 6mm is considered too inflexible to manoeuvre around and into the data logging system, especially where 10 or more thermocouples are concerned. Ten 4.5mm diameter MI thermocouples may be just possible to fit onto the data logger and fit back in the thermal protection, but the heat transfer along the metallic sheath and back into the datalogger cavity must be considered. The surface area of the sheath of a 4.5mm diameter MI thermocouple is approximately 50% greater than a 3mm diameter probe, and would therefore conduct far more heat back into a system. The best compromise, for accuracy, flexibility, and minimal heat transfer, is 3mm diameter MI thermocouple, and it is not surprisingly the most commonly used for these trials.

### Accurate probe positioning in slab/billet

When considering measurement accuracy in a reheat application the choice of thermocouple, although important, is not the

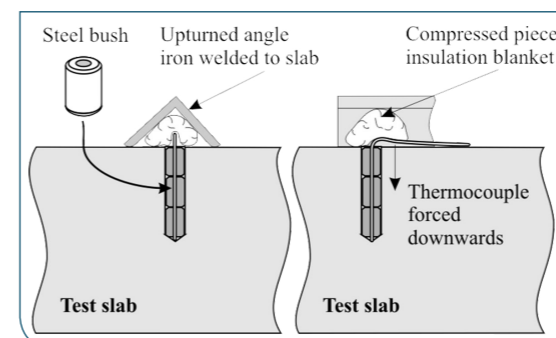


Figure 3: Thermocouple fixing methodology recommended to ensure that MI thermocouples measure accurately at the required depth in the slab/billet and are secured in place during the profile run

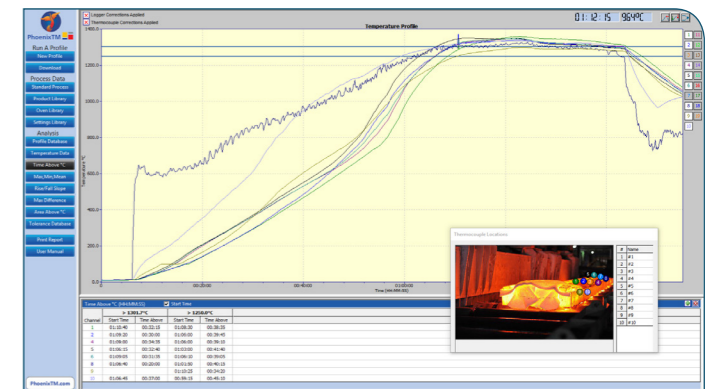


Figure 4: PhoenixTM Thermal View Plus Software showing a typical 'thru-process' slab/billet temperature profile trace. The profile traces show the variation of temperature at different locations in the slab/billet and also the furnace environmental temperature. Such data can be imported directly into a furnace controller model to allow optimisation and validation

only consideration which needs to be made. Positioning of the thermocouple tip accurately at the slab depth required needs to be done with care. Drilling a 3 x 200mm hole to position the MI thermocouple is very difficult. To make this operation easier it is recommended that a 20mm pilot hole is created which is then filled using steel bushes guiding the thermocouple tip to the required measurement point (See Figure 3).

### Fixing of thermocouples over the slab

Mineral insulated thermocouples have a residual springiness and therefore need to be held in contact with the slab being monitored to ensure that the measurement point of the thermocouple 'hot junction' remains in contact with the slab at the depth required. It is recommended that insulated thermocouples are held in position by packing an insulating blanket beneath a piece of upturned angle iron and 'tack welding' this to the slab surface (See Figure 3). This action not only secures the thermocouple in place but can significantly reduce the risk of 'shunt impedance' errors, by reducing the temperature difference between the hot junction and thermocouple itself running through the furnace environment.

### Applying 'thru-process' temperature data to validate mathematical models – the benefits

By applying accurate profile data to mathematical models, targeted roughing mill exit temperatures can be set to obtain a desired furnace drop out temperature throughout the product thickness. Accurate control of such variables allows a successful rolling operation with minimal scale build up maximising mill yields, saving energy and maximising production throughput. By accurate optimisation and reduction of the furnace operating temperature, the furnace life can be extended. At the same time under temperature products can be prevented, further protecting down-stream processing machinery.

### Overview

The PhoenixTM 'thru-process' slab/billet reheat system offers an accurate, rugged and reliable solution for performing product temperature profiling of slab/billet reheat processes, providing the means to understand, control, optimise and certify the furnace and allow accurate optimisation of mathematical models applied.

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