PSR: GLASS TEMPERATURE MEASUREMENT IN FOREHEARTHS AND DISTRIBUTORS

Precise forehearth and distributor temperature control is essential if consistent feeder operation and efficient glassware production are to be maintained. To control the glass temperature it must be accurately measured. Here we describe and compare the temperature sensors recommended and used in our forehearth and distributor systems.

The function of the feeder forehearth is to provide gobs of glass to the forming machine at a constant, uniform temperature suitable for the particular forming process, at a constant weight and shape and at the required speed of the forming machine. The most important physical parameter for the forming process is the glass viscosity and as this varies on a logarithmic scale with glass temperature (small changes in temperature producing large changes in viscosity), precise forehearth temperature control is essential if consistent feeder operation and efficient glassware production are to be maintained.

The actual gob temperature is normally controlled indirectly by controlling the equalizing section temperature of the forehearth and measuring the gob temperature periodically with a portable infrared pyrometer. Some companies install thermocouples in the feeder spout but these temperature readings are significantly affected by the location of the thermocouple and the feeder tube rotation direction and speed. Although the gob temperature is of prime

Fig. 1 - A feeder forehearth providing gobs to the forming machine

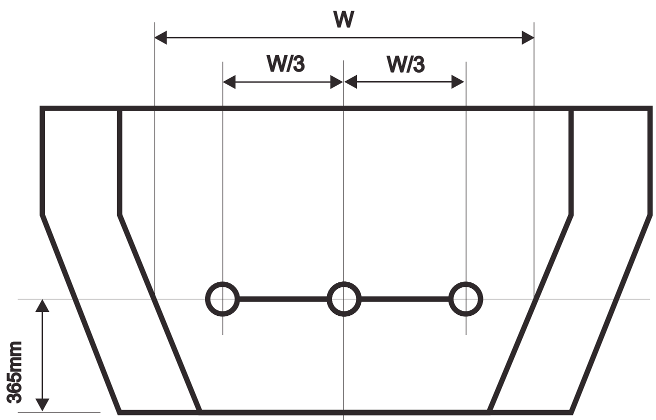
importance, many glass companies still do not measure this at all and rely entirely on the measurement and control of the equalizing section temperature.

The uniformity of the gob temperature can be evaluated on a qualitative basis by observing the formation of the gob preferably with the feeder tube stopped from rotating. This assumes that all the feeder expendable refractory parts have been correctly selected and installed and that the feeder mechanism has been correctly adjusted and is operating correctly. If the gob does not develop straight from the orifice and curls to one side this indicates that the gob is cold on the side to which the gob curls. If the gob curls towards the forehearth then the bottom glass is too cold and the rear cooling sections need increasing in temperature.

If the gob curls away from the forehearth then the bottom temperature is too high and the rear cooling sections need to be reduced in temperature.

Before the development and widespread use of suitable permanently installed tri-level (triplex) thermocouples, these observations were used for setting up the forehearth zone temperatures.

The use of temporary portable tri-level thermocouples at job changes alongside these observations eventually lead to the use of permanently installed tri-level thermocouples.



PSR standard thermocouple positions

TRI-LEVEL THERMOCOUPLES

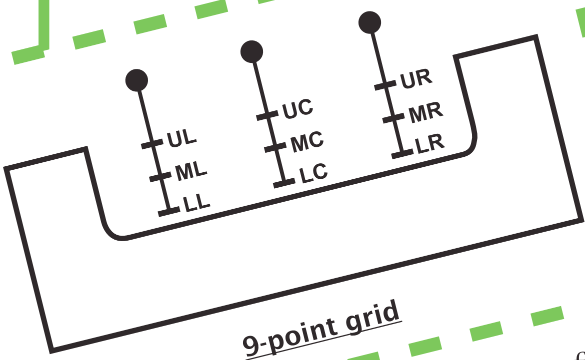
The thermal homogeneity of the glass entering the spout can be used as a quantitative guide to the uniformity of the gob temperature. This is evaluated by installing three tri-level (triplex) thermocouples through the equalizing section superstructure across the spout entrance. These thermocouples have three hot junctions located at one inch (25 millimetres) off the channel bottom (Lower), in the middle of the glass stream (Middle) and one inch (25 millimetres) below the glass surface (Upper).

They are normally arranged in a nine-point grid with one on the centre line of the forehearth and one on either side (Left and Right) at a distance equal to a third of the channel width from the centre line. The thermocouples should be as close to the spout entrance as possible but not so close that their readings are readily affected by changes in the direction and speed of rotation of the feeder tube or rotors. They should be located between burner positions to prevent possible damage to the side thermocouple sheaths by flame impingement, with a peephole positioned to allow viewing of the thermocouples. The thermocouples are typically located 14.3/8 inches (365 millimetres) back from the spout entrance.

The spread of temperatures

over the nine-point grid can be expressed mathematically as a percentage thermal homogeneity efficiency figure as adopted by several glass companies. In comparing these thermal homogeneity figures the location of the thermocouples and the method of calculation must be taken into account.

PSR uses the following 9-point and 5-point thermal homogeneity calculations:



For the 9-point grid, six positive horizontal temperature differences 'ΔH' are calculated from the values

(U.C.–U.L.),
(U.C.–U.R.),
(M.C.–M.L.),
(M.C– M.R.),
(L.C.–L.L.) and
(L.C.–L.R.)

by subtracting the lowest value from the highest value.

Three positive vertical temperature differences 'ΔV' are calculated from the highest and lowest values of

(U.L., M.L. and L.L.),
(U.C., M.C. and L.C.) and
(U.R., M.R. and L.R.)

by subtracting the lowest value from the highest value.

The 9-point forehearth thermal homogeneity efficiency is then calculated as follows:

9-Point Thermal Homogeneity Efficiency

(%) = [1–(ΔH + ΔV)/M.C.] x 100.

The triangular area formed by the Upper Centre (U.C.), Lower Left (L.L.) and Lower Right (L.R.) thermocouple junctions contains the glass primarily used to form the gob and it is considered that these temperatures have a direct bearing on gob temperature distribution and ultimately on the glass distribution in the article being manufactured. For this reason many glass companies only use the five points within this triangle in the calculation.

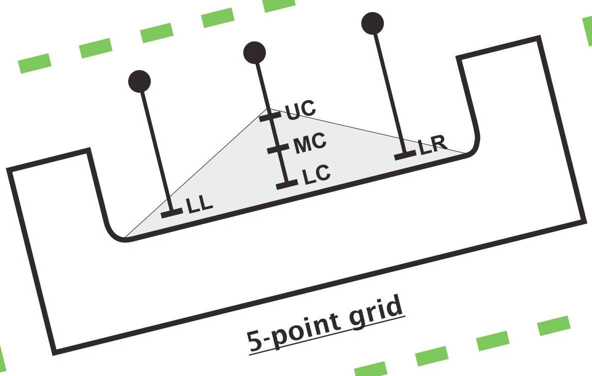
This allows the upper and middle sidewall temperatures to be operated at higher temperatures if necessary to increase the lower sidewall temperatures without producing a lower thermal homogeneity efficiency figure.

For the 5-point grid, two positive horizontal temperature differences 'ΔH' are calculated from the values

(L.C. – L.L.) and (L.C.– L.R.)

by subtracting the lowest value from the highest value.

One positive vertical temperature difference 'ΔV' is calculated from the highest and lowest values of (U.C., M.C. and L.C.) by subtracting the lowest value from the highest value.



The 5-point forehearth thermal homogeneity efficiency is then calculated as follows:

5-Point Thermal Homogeneity Efficiency (%) = [1–3 x (ΔH + ΔV)/M.C.] x 100.

As in the 5-point calculation there are only two horizontal temperature differences and one vertical temperature difference compared with the six horizontal temperature differences and three vertical temperature differences in the 9 point calculation, the temperature differences are multiplied by 3 to make the typical differences of the 5 points represent the total differences of the 9 points and to make the 9-point and 5-point calculations mathematically equivalent.

Other methods of calculating the forehearth thermal homogeneity efficiency value are used by different companies but we believe that the versions of the calculations described above best represent the glass thermal homogeneity because if all 9 or 5 thermocouple temperatures are the same both thermal homogeneity efficiency values calculate at 100 per cent and values greater than 100 per cent are not possible. Other calculations attaching more importance to the sidewall temperatures being hotter than the centre temperatures can provide thermal homogeneity efficiency values greater than 100 per cent. The logic behind this is that as these temperatures are measured a distance back from the spout the side temperatures will cool faster than the centre line temperatures due to the greater heat losses. So if the side temperatures start off hotter than the centre line temperatures it is more likely that the temperatures across the glass width will be more even when the glass reaches the spout entrance. In some designs the centre line tri-level thermocouple is off-set further back upstream from the side tri-level thermocouples to effectively achieve the same result but with the objective of having the temperature readings equal and using the original thermal homogeneity efficiency calculation.

These nine or five thermocouple temperatures provide the only quantitative basis for setting up a forehearth and its associated distributor zone set point temperatures with the objective normally of obtaining the best vertical and horizontal glass thermal homogeneity at the spout entrance.

If the feeder tube is rotated too quickly it can result in the formation of a vortex and a resultant build-up of colder stagnant glass on the side to which the tube rotates, particularly if the full flow capacity of the forehearth and spout is not being utilized. Under these circumstances if the direction of rotation of the feeder tube is reversed the lower temperatures will change to the opposite side of the forehearth. The faster the rotation of the feeder tube, the greater the temperature difference will become between the two sides of the forehearth. It is generally recommended that the feeder tube or rotors be rotated as slowly as possible and not faster than about three revolutions per minute.

THERMOCOUPLE DESIGN

Thermocouple suppliers have worked closely with glass companies and forehearth suppliers over many years to develop reliable triplex thermocouple designs. PSR uses a high specification triplex thermocouple design providing long life and long-term accuracy and stability. This basic design has been produced by Engelhard (now BASF) for over 30 years. Although these triplex thermocouples have a high initial cost they are capable of operating for a complete furnace campaign and can be considered as an investment as a high proportion (typically 95 per cent) of the precious metal can be recovered for recycling and the significant scrap value refunded or offset against the purchase of new replacement thermocouples.

Type B thermocouple elements (Platinum– 30 per cent Rhodium +ve conductor and Platinum–6 per cent Rhodium –ve conductor) are used specially manufactured to Tolerance Class 1 which is from 0 to 1100°C ± 1·0°C and from 1100 to 1600°C ± 1 + 0·003 (t–1100)°C.

Normally Type B thermocouples are only manufactured to Tolerance Class 2 which is 600 to 1700°C ± 0·0025t. Type R (Platinum – 13 per cent Rhodium +ve conductor and Platinum –ve conductor) and Type S (Platinum – 10 per cent Rhodium +ve conductor and Platinum –ve conductor) are normally manufactured to Tolerance Class 1. Type B thermocouples have advantages over commonly used Type R and S thermocouples in that Platinum – Rhodium alloys are used for both conductors and any migration of Rhodium due to evaporation and diffusion at high temperatures does not significantly affect the temperature reading during the life of the thermocouple whereas the pure Platinum conductor of Type R and Type S thermocouples can be contaminated by Rhodium migration to give significant off-set errors even after a short period of operation. Type B thermocouples also generate a much lower EMF voltage with temperature and have a negligible output over the range 0 to 50°C making cold junction compensation and the use of compensating cable less critical. Compensating cable can be supplied which is not as expensive because only high temperature copper-copper cable is required.

Type R and Type S compensating cable required for these thermocouples can also introduce an error unlike

Fig. 2 Tri-level thermocouples installed in PSR forehearth equalizing section

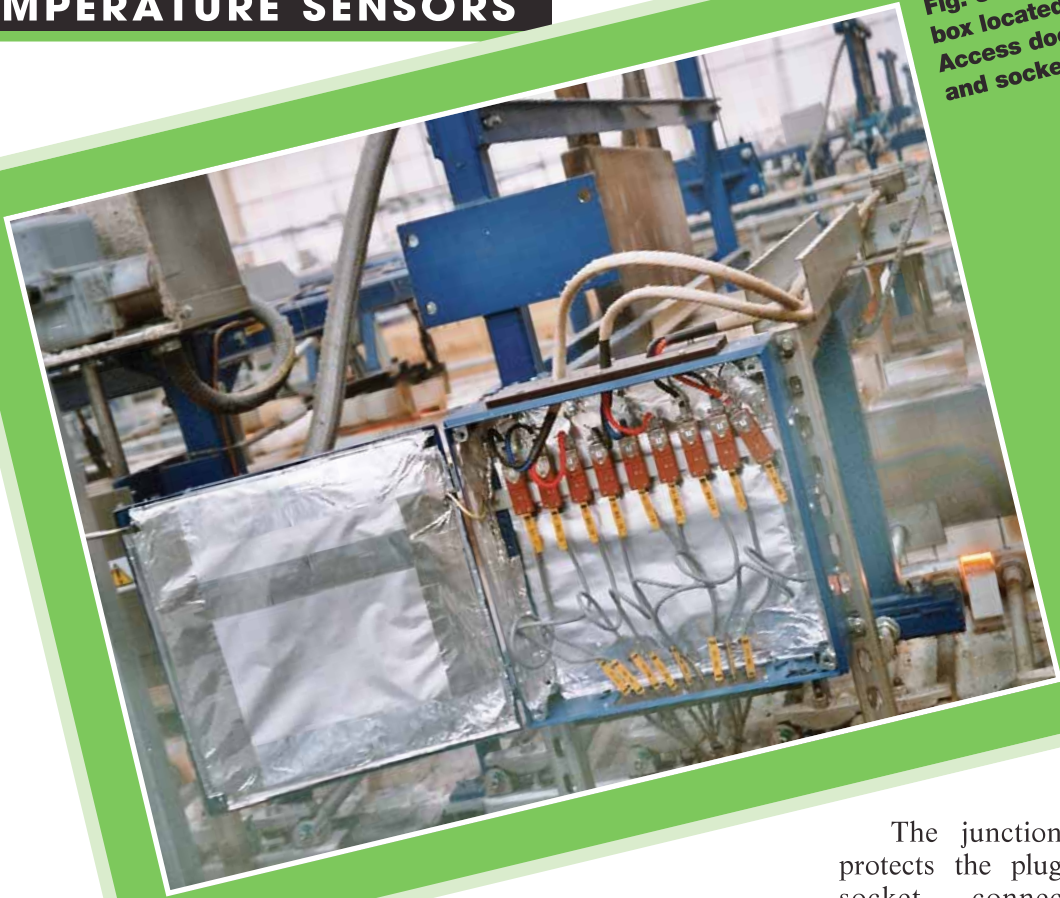


Fig. 3 - Thermocouple junction box located at side of forehearth. Access door is open to show plug and socket connections

the copper-copper cable used with Type B thermocouples. For example Type R and Type S compensating cable up to a temperature of 1000°C and with the connection to the thermocouple between 0 and 100°C has a tolerance of ± 2·5°C. Type R and Type S thermocouples were popular for use with the older analogue instrumentation due to their higher millivolt output signals which are easier to measure but this is not now a consideration with modern microprocessor based digital instrumentation.

In this thermocouple design there are no connections in the thermocouple head with the precious metal element wires passing directly through the sealed thermocouple head and extending for 2 metres so that the connection to the field wiring can be made in an insulated and sealed junction box in a cooler location at the side of the forehearth.

This connection is made with plugs and sockets which are included with the thermocouple. This avoids any junction errors due to connections in the thermocouple head being at the high ambient temperature directly above the forehearth. The two-metre long precious metal extension leads (not compensating cable) are individually covered in a heat resistant glass fibre sleeve together with an overall glass fibre sleeve covering all three leads.

For junction identification the Upper junction is sleeved in black and is numbered 1 on the plug, the Middle junction is sleeved in blue and is numbered 2 on the plug and the Lower junction is sleeved in red and is numbered 3 on the plug. The numbers are engraved on the plugs to provide a permanent identification. A sealed and insulated junction box is included in our supply together with the necessary thermocouple mounting brackets and insulators.

The junction box protects the plug and socket connections from oxidation and oil contamination due to the relatively high ambient temperature and oily atmosphere around the forehearth. The mounting brackets hold the thermocouples in the correct position and shield the thermocouple heads from the heat from the forehearth superstructure and exhaust flues. The insulators isolate the thermocouples from the forehearth steelwork and mounting bracket to prevent any electrical interference from electric boosting systems.

The thermocouple has a 15-millimetre outside diameter and 10-millimetre inside diameter recrystallized alu-

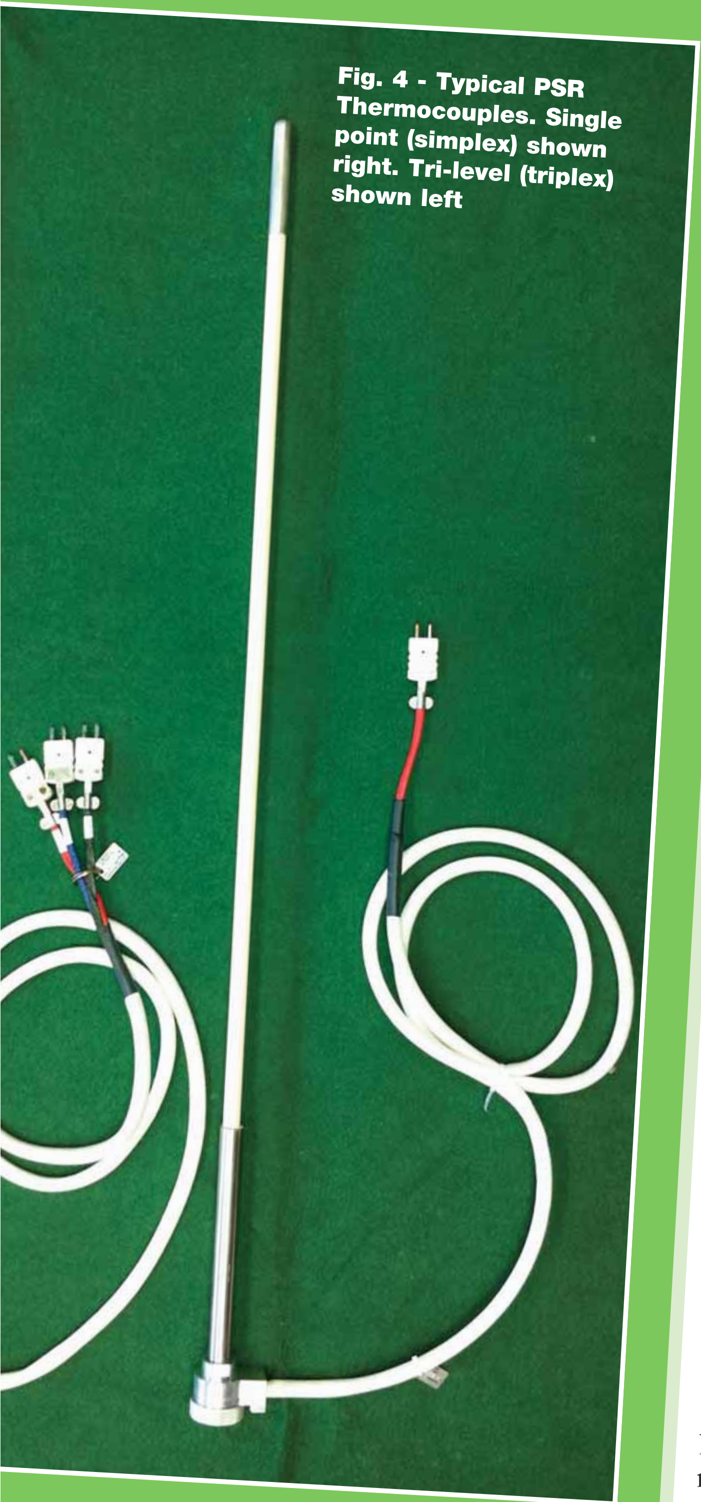


Fig. 4 - Typical PSR Thermocouples. Single point (simplex) shown right. Tri-level (triplex) shown left

mina sheath protected from the glass with an 8-inch (203 millimetres) long, 0·38-millimetre thick Oxide Dispersion Strengthened (ODS) Platinum thimble thickened to 1·00 millimetres at the tip which is cemented and fired on to the recrystallized alumina sheath.

Unlike normal platinum and platinum-rhodium alloys which are corroded by amber glass and have a relatively short life, the ODS Platinum is suitable for use in all glass types and colours.

The three thermocouple junctions use 0·5 millimetres thick Type B thermocouple wire within single recrystallized alumina twin bore insulators.

The three junctions are normally located 1/2 inch (13 millimetres), 2.1/2 inches (64 millimetres) and 4.1/2 inches (114 millimetres) from the tip of the thermocouple. The thermocouple is normally installed 1/2 inch (13 millimetres) off the channel block base being designed for use in a nominal 6 inches (152 millimetres) glass depth. The thermocouple can be lowered the 1/2 inch (13 millimetres) to the channel base if necessary to accommodate a lower nominal glass depth of 5.1/2 inches (140 millimetres) or even 5 inches (127 millimetres) but other thermocouple junction locations for different glass depths can also be provided. If the thermocouple is to be installed on the channel bottom then the weight of the thermocouple must be supported by the thermocouple bracket to prevent deformation of the thimble over time. The thickened thimble bottom protects against possible erosion due to vibration.

The overall length of our standard triplex thermocouple for installation across the spout entrance in an equalizing section is 36 inches (915 millimetres) excluding the thermocouple head made up of an 8 inches (203 millimetres) long, 22 millimetres outside diameter Inconel backing tube and a 28 inches (711 millimetres) long, 15 millimetres outside diameter, 10 millimetres inside diameter recrystallized alumina sheath. A 40 millimetres diameter access hole is required in the forehearth roof for installation of the thermocouple.

Longer thermocouples are supplied for other locations such as the forehearth entrance. Longer ODS Platinum thimbles are used for greater glass depths.

ADVANCED CONTROL STRATEGIES

The Upper Centre triplex thermocouple junction is used as the control sensor for the equalizing section. This must not be located much more than 1 inch (25 millimetres) below the glass surface, particularly for coloured glasses, otherwise temperature control cycling will occur due to excessive process lag. In our advanced temperature control systems the Middle Centre and Lower Centre junctions are used in secondary Cascade control loops to trim the cooling section set point temperatures, automatically optimizing the centre line vertical glass temperature homogeneity at the spout entrance.

The Lower Left and Lower Right junctions are used in secondary Trim control loops to trim the left and right-hand side firing, automatically optimizing the horizontal glass temperature homogeneity. The secondary Cascade and Trim control loops operating together automatically optimise the overall thermal homogeneity at the spout entrance.

INFRA-RED FIBROPTIC THERMOMETERS

For measurement of forehearth cooling section temperatures and distributor section temperatures including the throat riser PSR normally recommends and uses infra-red fibroptic thermometers.

The Land Fibroptic Model FG supplied by Land Instruments is a popular analogue instrument of which we have supplied many units over the years although for the past 9 years we have used the Infratherm IS 50-LO/GL, a digital instrument supplied by Lumasense Technologies (formerly Impac). The thermometer consists of an optical head lens mounted in a purge air assembly which is sighted vertically from above the forehearth or distributor roof onto the glass surface through an Inconel sighting tube. The optical head is connected to the thermometer processor unit via a 5-metre long stainless steel coated fibroptic light guide which allows the processor unit to be mounted in a junction box in a cooler location at the side of the forehearth or distributor rather than on top of the forehearth. This allows the processor unit to operate accurately without the need for air or water cooling as was required with the infra-red pyrometers originally used over 30 years ago. The maximum ambient temperature for the optical head and light guide is 250°C whereas for the processor unit it is 70°C. The purge air assembly protects the optical head objective lens surface from contamination with dust or moisture.

It requires a supply of instrument quality (dry and oil free) compressed air at an approximate volume of 65 to 100 litres per minute (4 to 6 cubic metres per hour) and generates a cone shaped air stream.

The optical head is connected to the purge air assembly with a quick release bayonet connector allowing easy removal for lens checking and cleaning as well as for viewing down the sighting tube for checking against a portable infrared thermometer.

A purge air control panel incorporating a pressure regulator, water filter, oil filter, individual flow indicator/regulator rotameter for each fibroptic and low pressure switch for remote alarm monitoring is included in our supply to ensure an adequate supply of purge air to each fibroptic thermometer. A 610 millimetres long Inconel sighting tube is used to allow the optical head to be mounted high on top of the forehearth superstructure steelwork on a special mounting bracket/heat shield to protect the optical head and light guide from the heat exhausted from the combustion and cooling flues. The narrow sighting angle of the thermometer objective lens allows sighting within the 27 millimetres internal diameter Inconel sighting tube and the 40 millimetres diameter access hole in the forehearth roof block to the glass surface. The Inconel sighting tube passes through a 134 millimetres thick fibroptic sighting block above the forehearth roof block to protect the surrounding roof block insulation and enters 25 millimetres into the external face of the roof block to ensure that the sighting block is correctly aligned with the access hole in the roof block. The infrared radia-

Fig. 5 - Fibroptic thermometer, purge air assembly and inconel sighting tube located above the forehearth

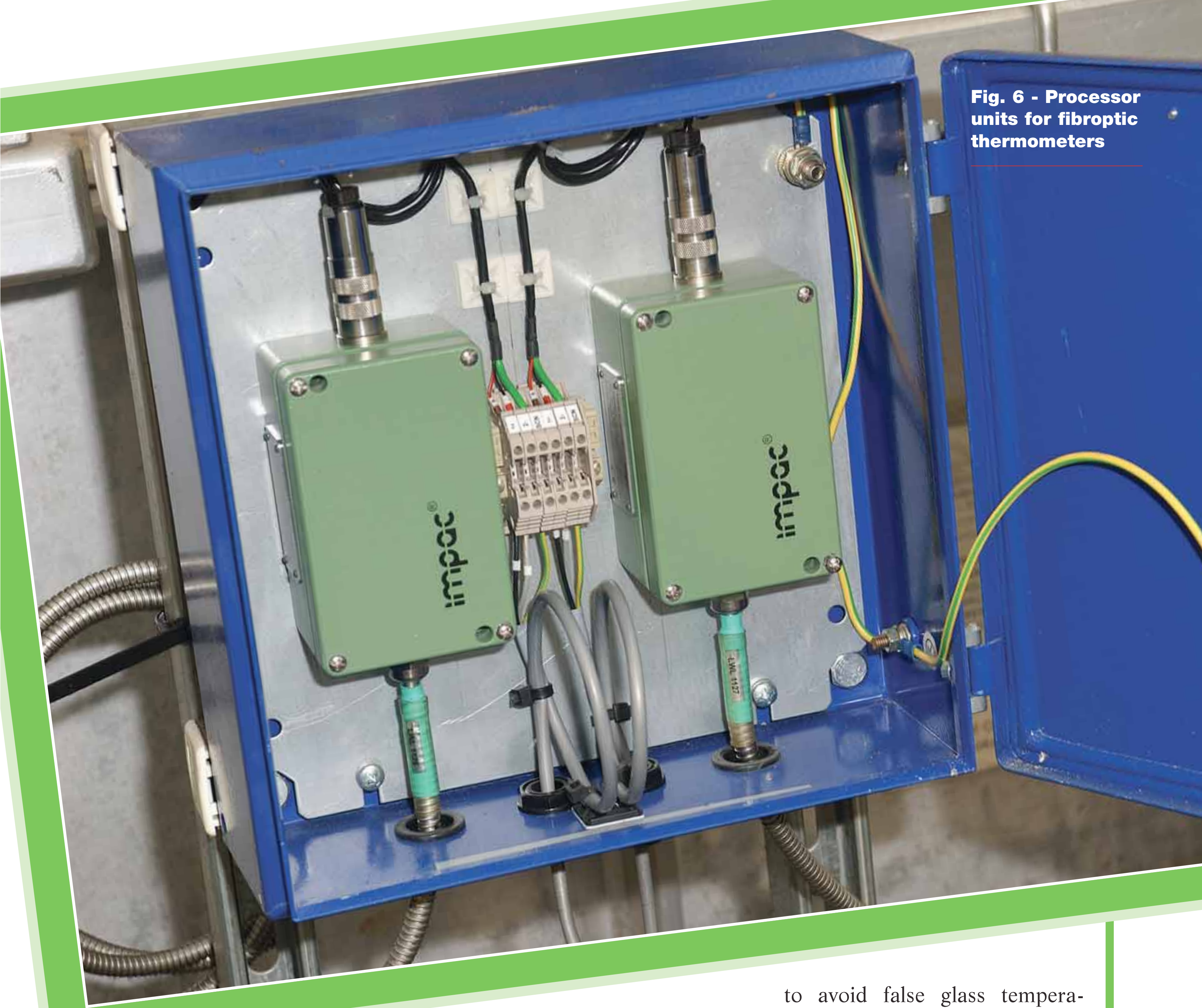


Fig. 6 - Processor units for fibroptic thermometers

tion is transmitted through the fibre optic light guide to the processor unit. Transmission through the multi-fibre optic light guide is based on the principle of total internal reflection by the boundary surfaces of the glass fibres which is practically free from any losses.

During installation the light guide must be adequately supported and the bend radius must not be less than 50 millimetres to prevent damage to the glass fibres. The processor unit consists of the infra-red detector and signal processing circuitry.

The infra-red detector is a silicon photovoltaic cell which is very stable with ambient temperature and time. Its spectral response is in the range 0·8 to 1·1 micron which ensures that it is unaffected by changes in the combustion atmosphere in its sighting path as the water vapour and carbon dioxide in the combustion atmosphere radiate at wavelengths outside the sensor's spectral range.

Much earlier Radiamatic pyrometers used extensively in the glass industry over 50 years ago were total radiation pyrometers using thermopile devices which were sensitive to all wavelengths.

These required the use of an air purged refractory sighting tube extending to within a short distance from the glass surface to avoid false glass temperature readings due to changes in the combustion products in the pyrometer's sighting path.

The fibroptic thermometer has a temperature range of 600 to 1800°C suitable for many applications but for forehearth and distributor temperature measurement a sub-range is set of 1000 to 1400°C. The processor unit requires a 24 Volt DC power supply from the temperature control system and provides a linearized 4 to 20 milliamp signal representing the temperature range 1000 to 1400°C which is suitable for direct input into a temperature control system. It has a test switch which outputs a mid-range signal of 12 milliamps to test the correct connection of the field wiring and configu-

Fig. 7 - Purge air control panel for 6 fibroptic thermometers

ration of the control system temperature controllers and indicators.

The signal processing circuitry is digital allowing easy and quick setting up of the instrument using a digital interface to a PC running the configuration software. To complement the instrument a calibration source is available allowing quick and easy checking and adjustment of the thermometers.

The fibroptic thermometer has a modular construction allowing easy replacement of major component parts, in some cases without the need to return the instrument to the manufacturer.

The fibroptic thermometer measures essentially the surface glass temperature (the top 25 millimetres for white flint glass, 5 millimetres for amber glass and 4 millimetres for green glass) and is installed sighting vertically on the glass surface at the end of each control zone.

To obtain a correct temperature measurement of an object with a radiation thermometer it is necessary to set the emissivity value for the object.

The emissivity of an object is a measure of the object's emission and absorption of radiation at a particular wavelength and temperature compared to a perfect black body which has an emissivity of 100 per cent. As the thermometer is sighting at right angles to the glass surface in a totally enclosed forehearth chamber the emissivity setting on the instrument is set at 100 per cent as in this situation the glass approximates to a total black body.

SINGLE POINT THERMOCOUPLES

Some customers prefer to use single point thermocouples rather than fibroptic thermometers in the cooling sections. In this case an equivalent single point (simplex) thermocouple design to the same high specification as the tri-level (triplex) thermocouple design can be supplied.

The single point thermocouples have a shorter ODS Platinum thimble as the single junction is only installed 1 inch (25 millimetres) into the glass surface but they have a longer overall length as they are mounted in brackets/heat shields high on the superstructure steelwork in the same location as the fibroptics would be installed to protect the thermocouple head from the heat from the combustion and cooling exhausts. A peephole is positioned opposite the thermocouple location to allow correct positioning of the thermocouple in the glass.

The thermocouple is lowered by a colleague whilst being viewed through the peephole. When the thermocouple tip touches the glass surface as indicated by the tip of the thermocouple merging with its own reflection in the glass surface the thermocouple backing tube is marked and then the thermocouple is lowered a further 11/2 inches (38 millimetres) to put the thermocouple junction 1 inch (25 millimetres) into the glass surface.

Some customers also use tri-level (triplex) thermocouples in the cooling sections but whilst these provide additional information to show the temperature gradients through the glass depth along the length of the forehearth this is an expensive option and does not really provide any information that could not be ascertained from the resultant tri-level thermocouple temperatures at the spout entrance.

PSR has used both fibroptic thermometers and single point thermocouples in cooling sections and on balance prefers to use the fibroptic thermometers as they are a non-contact sensor.

Both sensors provide good results and troublefree operation providing that they are installed correctly. Each sensor has its own advantages and disadvantages which are summarized and compared below.

ADVANTAGES AND DISADVANTAGES OF INFRA-RED THERMOMETERS

- Infra-red thermometers provide non-contact temperature measurement and are therefore not damaged by and cannot contaminate the glass. Their readings cannot be affected by electric boosting in the glass.
- Infra-red thermometer sensors are stable and do not deteriorate with time. Their calibration can be checked and re-set if necessary. Good installation and maintenance techniques can provide an almost unlimited lifespan.
- Infra-red thermometers require an instrument quality compressed air supply for purging of the objective lens and a 24 Volt D.C. power supply for the processor unit.
- Infra-red thermometers provide a high level, linear 4 to 20 milliamp output signal that is less affected by electrical interference than a thermocouple millivolt signal and which can easily be scaled to provide improved signal resolution in a temperature control system.
- Infra-red thermometers have a fast response time reacting to temperature changes much faster than a thermocouple.
- Infra-red thermometers measure essentially the surface glass temperature and cannot measure the temperature at different points throughout the glass depth.
- However, as all heat transfer takes place through the glass surface infra-red thermometers are appropriate for controlling forehearth and distributor zone temperatures.
- Infra-red thermometers can be used in throat riser areas to measure the entrance temperature to the distributor from the furnace providing that no cooling is employed over the throat riser section.
- The measurement of the surface glass temperature is important in cooling sections to ensure that the glass surface is not being overcooled.
- Infra-red thermometers always measure the glass surface temperature irrespective of changes in the furnace glass level.
- Disruption to the glass surface as can occur in the vicinity of stirrers can result in a fluctuation in the temperature measured by an infra-red thermometer due to surface optical effects.

ADVANTAGES AND DISADVANTAGES OF THERMOCOUPLES

- Thermocouples are in contact with the glass and can be corroded and damaged by the glass flow and any foreign materials such as stones passing through with the glass. The thermocouple sheath needs to be protected with an appropriate platinum thimble to prevent corrosion by the glass and provide an acceptable lifespan.
- Thermocouples can be subject to electrical interference from electric boosting in the glass and need to be isolated from the forehearth and mounting steelwork.
- Thermocouple outputs can deteriorate with time at high temperatures and the thermocouple type should be selected to minimize this affect.
- Thermocouple calibration cannot be practically checked and cannot be re-set. Faulty thermocouples have to be replaced.
- Good thermocouple design and installation can provide a long but finite lifespan.
- The precious metal content of the thermocouples can be recovered for recycling and the significant scrap value refunded or offset against the purchase of new replacement thermocouples.
- Thermocouples require no additional services.
- Thermocouple junctions used for zone temperature measurement and control must be located no more than 1 inch (25 millimetres) below the glass surface otherwise temperature control cycling can occur due to the excessive process lag between changes in the heating or cooling and changes in the measured temperature.
- The glass surface temperature can be significantly different from the temperature 1 inch (25 millimetres) below the glass surface particularly when cooling coloured glasses.
- As the thermocouple junctions are set at a particular distance below the glass surface under specific operating conditions changes in the glass level due

to hydraulic head loss along the forehearth at different forehearth throughputs will result in changes in the measurement point location and the measured temperature.

- Similarly changes in the controlled furnace glass level will result in changes in the measurement point location and the measured temperature.
- The furnace glass level must be controlled to ± 0·010 inches (± 0·25 millimetres) or better for successful thermocouple control of forehearths and distributors. Glass level changes in excess of these values will result in temperature upsets due to the measurement points being closer or further away from the glass surface.
- Thermocouples such as tri-level thermocouples having junctions at different levels can measure the glass temperature throughout the glass depth for glass thermal homogeneity evaluation and to provide a basis on which to set up forehearth and distributor zone temperatures.
- Suitable thermocouples with long protection thimbles can be used in heavily cooled distributor throat riser areas to measure the glass temperature entering the distributor from the furnace at glass depths not affected by the cooling which may be some 12 inches (305 millimetres) below the glass surface.

At the beginning of this article we stated that the function of the feeder forehearth is to provide gobs of glass to the forming machine at a constant, uniform temperature suitable for the particular forming process, at a constant weight and shape and at the required speed of the forming machine but that the gob temperature and uniformity is normally controlled indirectly by controlling the equalizing section temperature and the glass thermal homogeneity at the spout entrance.

The actual gob temperature not only depends on the glass temperature and thermal homogeneity as measured in the equalizing section at the spout entrance but also on the following factors:

- The levels of substructure and superstructure insulation in the forehearth equalizing section and spout.
- The orifice ring size and insulation.
- The atmospheric conditions around the feeder spout as it determines heat losses.
- The spout firing level. The spout firing is normally manually set at a fixed firing level to compensate for the heat losses at the spout so that the glass is generally neither heated nor allowed to cool greatly from the temperature in the equalizing section.
- The glass depth in the equalizing section and spout which determines the glass residence time and consequent heat loss between the measurement point in the equalizing section and the orifice.
- The forehearth pull which determines the glass residence time and consequent heat loss between the measurement point in the equalizing section and the orifice.
- The gob size and weight.
- The feeder tube direction and speed of rotation as it affects the glass flow into and within the feeder spout.
- The feeder plunger height, stroke and action as it pushes the glass through the orifice.
- The shear mechanism operation in cutting the gobs and shear cooling spray which may locally cool the spout and orifice ring.

As can be seen there are many other factors that determine the gob temperature and as this is the final opportunity to control the temperature of the glass and hence the viscosity of the glass entering the forming operation we consider that measurement and control of the gob temperature is of prime importance for the forming process and should not be ignored.

CONTINUOUS GOB MEASUREMENT AND CONTROL

Continuous gob temperature measurement and control using infra-red thermometers as well as gob monitoring by thermal imaging has been possible for many years but not widely adopted in the industry. For gob temperature measurement a two colour infra-red thermometer is normally used, measuring at two different wavelengths and comparing the ratio to minimize the affects of shear spray, steam and smoke on the reading and a peak picker is used to hold the maximum temperature and ignore the shearing. These infrared thermometers are generally sighted on the gob at the orifice and measure a similar temperature to a portable infra-red thermometer. However, modern parallel shear mechanisms make it very difficult to view the gob near the orifice ring to accurately measure the gob temperature in this way.

PSR has participated in gob temperature measurement and control trials using the high specification BASF Exactus GT infra-red thermometer. The advanced, high speed BASF Exactus GT infra-red thermometer has such a fast response time (1000 readings per second) that it can not only measure the gob temperature in free fall

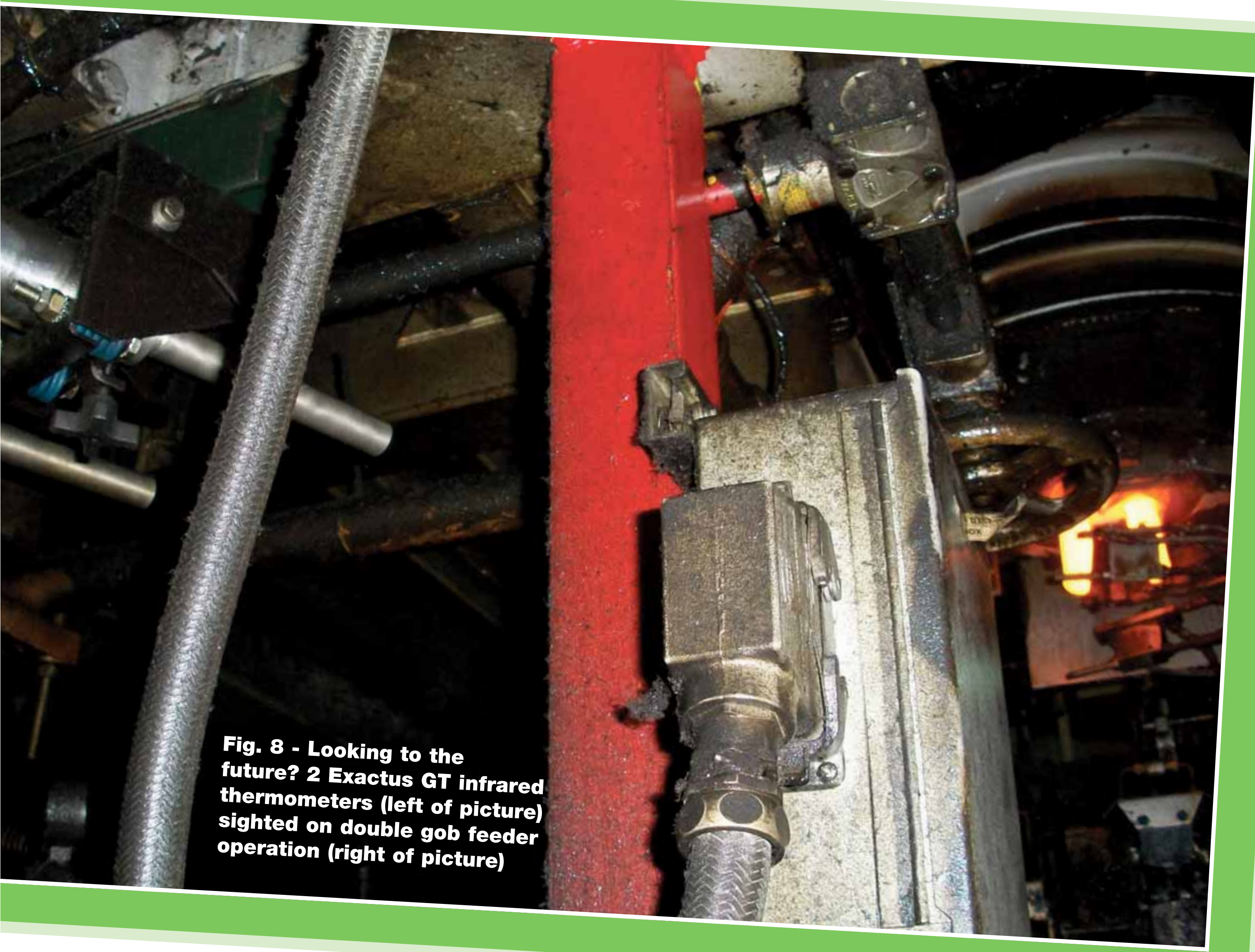


Fig. 8 - Looking to the future? 2 Exactus GT infrared thermometers (left of picture) sighted on double gob feeder operation (right of picture)

below the orifice and provide an accurate single average gob temperature, it can also measure the longitudinal temperature profile of each individual gob and this information can be used to analyse the gob forming process and its subsequent effect on the forming process.

Whilst the gob temperatures observed on our forehearths using our normal temperature control strategies have generally been steady and consistent on multiple gob applications, the implementation of gob temperature measurement and control can still contribute to a significant improvement in the glass condition for the forming process and eliminate an otherwise unknown and uncontrolled important parameter.

Alongside the gob temperature measurement trials we have also trialled Model-based Predictive Control algorithms provided by Advanced Control Solutions Inc (ACSI) and these applied to our normal temperature control strategies have proved to be capable of providing improved thermal homogeneity and gob temperature control as well as improved temperature control response at job changes. ■