Furnace Tracker®

Billet Reheat System

USER MANUAL

Issue 2

MA3210A

DATAPAQ®

A Fluke Company

Furnace Tracker® Billet Reheat System

User Manual

Issue 2

Datapaq® is the world's leading manufacturer of process temperature-monitoring instrumentation. The company maintains this leadership by continual development of its advanced, easy-to-use Tracker systems.

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DATAPAQ PART NO. MA3210A

SAFETY WARNINGS

For safe use of Datapaq equipment, always:

- Take care to follow its supplied instructions.
- Observe any warning signs shown on the equipment itself.

Indicates **potential hazard**.

On Datapaq equipment this normally warns of high temperature, but where you see the symbol you should consult the manual for further explanation.

Warns of **high temperatures**.

Where this symbol appears on Datapaq equipment, the surface of the equipment may be excessively hot (or excessively cold) and may thus cause skin burns.

Manual set in 10 pt Gill Sans.

User manuals are available in other languages; contact Datapaq for details.

European Union Directives

The following product types

TPaq21 Thermocouple Data Logger

manufactured by Datapaq Ltd.
Lothbury House, Cambridge CB5 8PB, UK
comply with the requirements of European Union directives as follows.

Directive 2004/108/EC Electromagnetic Compatibility (EMC)
Standards Applied

EN61326-1: 2006 – Group 1, Class B equipment (emissions section only), and Industrial Location Immunity (immunity section only).
CFR47: 2007 Class A – Code of Federal Regulations: Part 15 Subpart B, Radio Frequency Devices, Unintentional Radiators.

RoHS Compliance Datapaq temperature monitoring equipment is exempt from EU Directive 2002/95/EC (restriction of the use of certain hazardous substances in electrical and electronic equipment) under category 9 Monitoring and Control Instruments. This Datapaq product nevertheless uses RoHS-compliant components and manufacturing processes.

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Operating principle

The object of monitoring the billet reheat process is to study the temperature profile of the billet throughout its thickness as it progresses through the furnace. With this information, calculations can be made relating to the efficiency of the furnace and whether the billet is reaching the correct temperature for the subsequent rolling or piercing operation.

Referring to ***Diagram A***, thermocouples set at different levels within the thickness of the billet, send temperature information to a highly accurate data logger that travels with the billet, through the process. This eliminates the need for trailing thermocouples, which is the

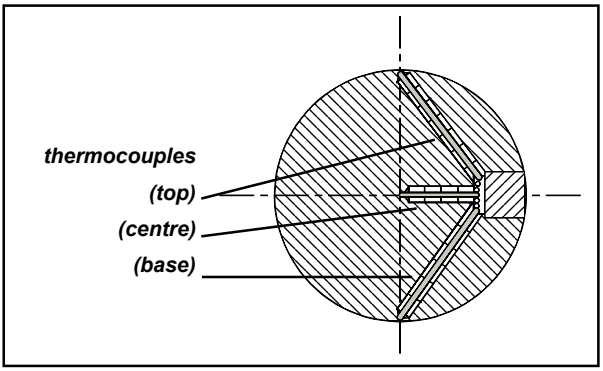


Diagram A

traditional method of monitoring these types of furnaces. Obviously, it would be impossible for the data logger to operate in the fierce heat of the furnace where temperatures can reach 1300°C, so it is protected by an evaporative thermal barrier as shown in ***Diagram B***.

The thermal protection consists of various layers of insulation, which slow down the passage of heat and allow different temperature levels to exist within the system. The first insulation layer consists of an alumina fibre blanket, which can operate in temperatures in excess of 1300°C and protects the evaporative thermal barrier. The outer case of the evaporative thermal barrier consists of high-grade micro porous insulation protected by a stainless steel casing. This high-grade insulation is limited to a temperature of 1050°C. Inside, water slowly boils off creating an environment where the temperature

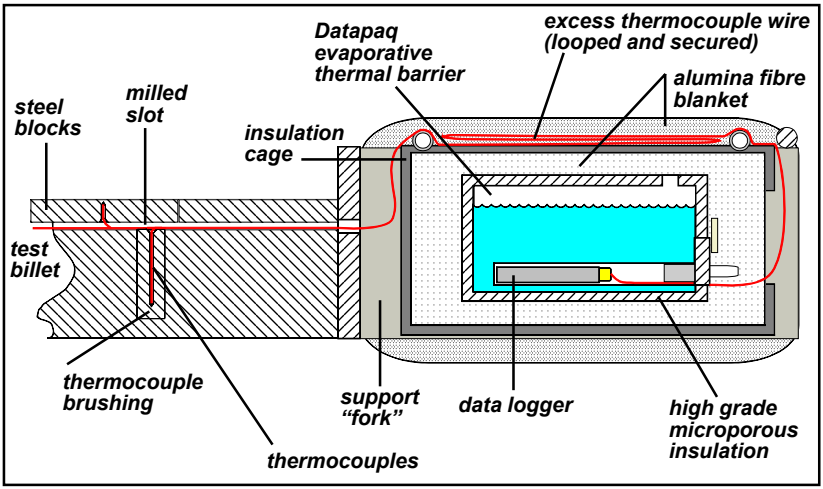


Diagram B

does not exceed 100°C. The data logger, situated inside the evaporative thermal barrier is designed to operate at temperatures up to 110°C and will therefore operate safely.

Diagram C shows the relative temperature levels inside the system while it is in the furnace.

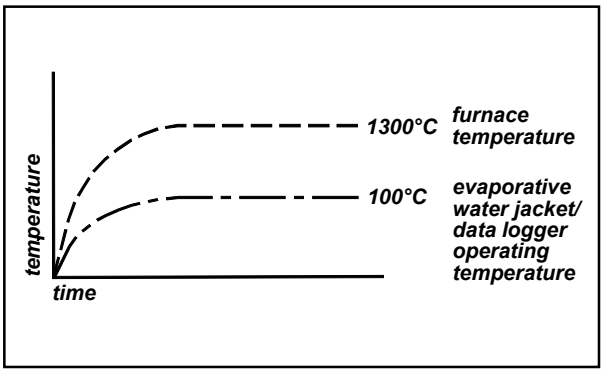


Diagram C

The thickness of the various insulating layers is carefully calculated to ensure optimum thermal performance during the processing time of the billet. The complete system is housed in a high-grade alloy cage that holds the outer ceramic blanket insulation in place and affords some mechanical protection.

Equipment required

The following is a list of the hardware supplied with the standard TB4066 Furnace Tracker Billet Reheat system:

System supplied by Datapaq:

1 x	TB9216	Insulation cage
1 x	TB4059	Evaporative water barrier
1 x	TP2116	10-channel Tpaq21 data logger
1 x	CI1008	Communications cable
10 x	PA0760	Thermocouples (lengths to be specified)
1 x	MA5500	Tpaq21 Data Logger User Manual
1 x	MA3210	Furnace Tracker Billet Reheat manual
1 x	CS1001	Hand held thermometer
1 x	CC0044	Aluminium carrying case for accessories
1 x	CS2009	Insulation pack comprising: CS2013A Saffil 1600 blanket roll, 96kg/m³, 25 mm thick x 0.61 m wide x 7.2 m long TB9225 set of templates for cutting additional insulation panels
1 x	TB9223	Thermocouple control clamp

NOTE ***Equipment above is for a standard TB4066 Billet Reheat System. Equipment in other systems, or in specially supplied systems, may differ.***

Thermocouple specification

Thermocouples must be purchased in specific lengths to suit your measuring positions. The full specification is as follows; type K mineral insulated, “Nicrobel” sheath, 3 mm diameter, insulated hot junction, to ANSI MC 96.1 (special limits of error). 50 mm (2”) of flexible PTFE “tails” are fitted at the pot seal, and these are terminated with a sub-miniature type K high temperature plastic plug. The plug and pot seal are filled with non-corrosive silicone rubber (see ***Diagram D***).

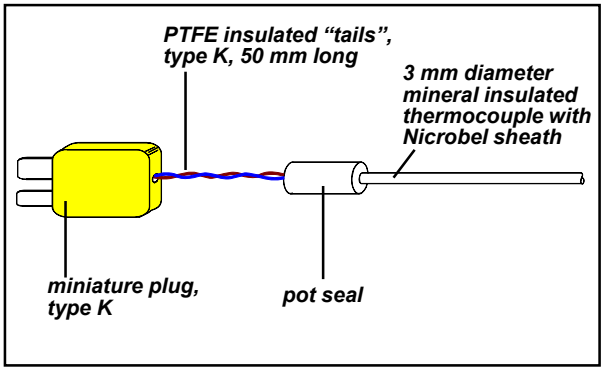


Diagram D

Equipment to be supplied by customer

Aluminised heat-protection suit comprising jacket and trousers with foot protection
High-temperature gauntlets (gloves)
Gold visor and head protection
Safety glasses
Protective gloves (for handling insulation)
Good-quality disposable approved dust mask or respirator
Long-blade knife (to cut insulation)
Long-blade scissors (to cut insulation)
Plastic funnel (to pour water into evaporative barrier)
Wire-cutters
Reel (20 m minimum) of nickel or other high-temperature wire (to secure loose insulation)

Preparation of the billet prior to the trial

It is necessary to secure the Datapaq system to the test billet for the trial. This is achieved by shortening the billet and attaching a “fork” to the end. The fork is designed to hold the Datapaq system in an upright position (avoiding water spillage from the evaporative thermal barrier), and affords the system some protection from mechanical shock as it is charged and discharged from the furnace (see ***Diagram E*** and ***Photograph 3***). These “forks” can be welded directly to the billet, or pinned to the billet via a “saddle”.

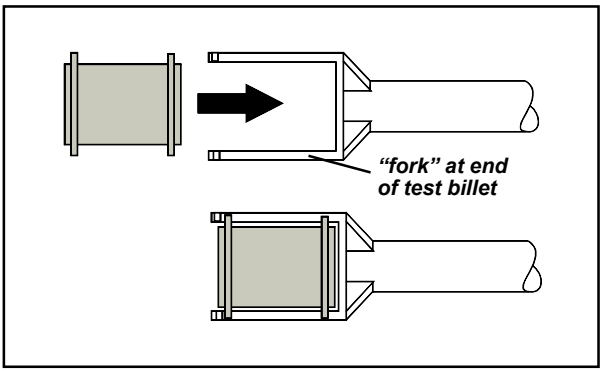


Diagram E

NOTE ***Manufacturing diagrams are avaliable for forks for all Billet Reheat Systems. These allow the user to maufacture the fork to carry their own specific thermal barrier.***

If the test billet travels through the furnace in close proximity to other billets (for example in a pusher or walking beam furnace), then it may be necessary to cut away part of the billets leading and trailing the test billet. In this way the system will travel normally through the furnace without impacting other billets (***Diagram F***).

The test billet may require further preparation (machining) depending on whether it is felt necessary to protect the thermocouples from the direct heat of the furnace.

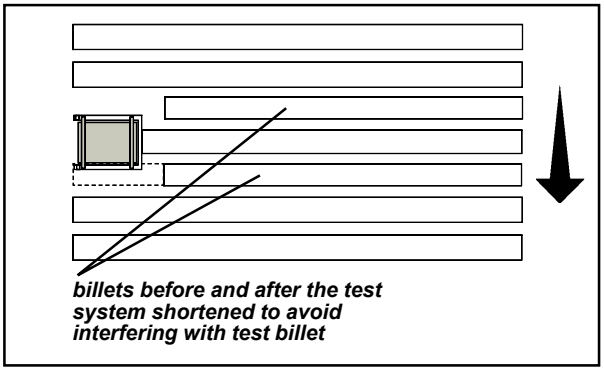


Diagram F

Protecting the body of the thermocouple is recommended to minimize any errors that may occur early in the trial due to the electrical “shunt effect”. This effect may occur above 1100°C when the body of the thermocouple is at higher temperature than the hot junction, which may be buried in the center of the billet (***Diagram G***).

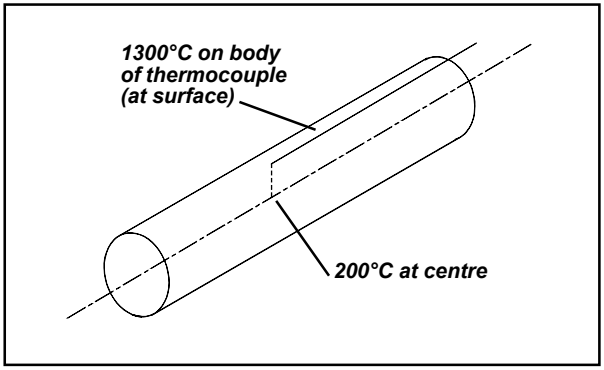


Diagram G

Shielding the thermocouple body is achieved by machining a slot longitudinally along the billet. The thermocouples are then set in this slot and covered with steel blocks (see ***Photographs 1–2***). This minimises the temperature difference between the hot junction of the thermocouple and the body of the thermocouple, and therefore minimises the errors that the “shunt effect” causes.

However, if it is not possible to carry out machining work on the test billet, then the thermocouples can be secured to the top of the billet (as shown in ***Photograph 4***). In this instance the body of the thermocouple is left exposed to the direct heat of the furnace which

may allow minor “shunt effect” errors at the start of the trial.

If protecting the body of the thermocouples is the chosen option then the billet must be machined as shown in ***Diagrams H and I***).

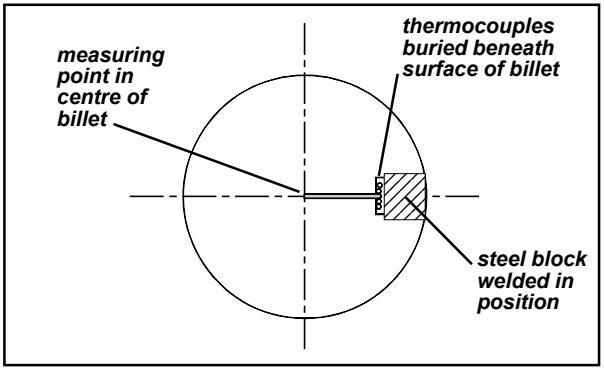


Diagram H

There are several points that should be noted:

The machining will take some time and should be started two or three weeks before taking delivery of the system, so that it will be ready at the commissioning date.

The billet may be reusable so the cost of machining can be spread over the number of times it is used.

The blocks that fit into the slot and protect the thermocouples should be a good sliding fit in the slot. They should butt together without any gaps, as excess heat in the thermocouple slot may give false readings.

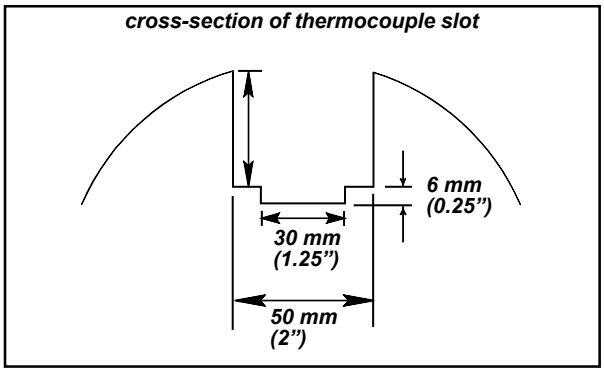


Diagram I

After the billet and blocks have been machined, oil the machined surfaces and store the billet where it will not be exposed to moisture. Corrosion of the machined surfaces will affect the fit of the blocks in the slot.

Drilling thermocouple holes in the billet

It is generally desirable to measure temperature at different depths within the billet. If the required measurement depths exceed 25 mm (1”) then it will be difficult to drill a hole small enough to take the thermocouple (3.2 mm or 1/8” diameter) without breaking the drill. So it is best to drill a bigger diameter hole and fill this with “bushes” to accept the thermocouples. These bushes can easily be drilled through with a small hole in a lathe. This is shown in detail in ***Diagram J***.

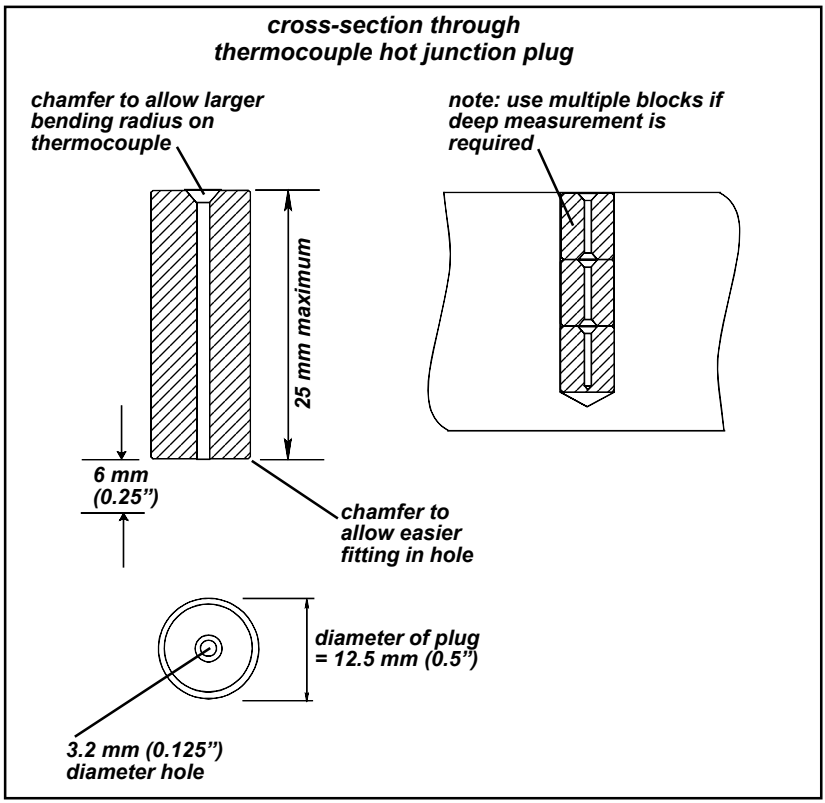


Diagram J

Finally, even though clearances may have been previously checked, it is worthwhile checking again when the test billet is completed to ensure the total height and width at the fork will have adequate clearance throughout the furnace. This is especially important when the billet passes through the doors at the entrance and exit of the furnace and passes beneath any “knuckle” (baffle) in the furnace roof (see ***Diagrams K and L***).

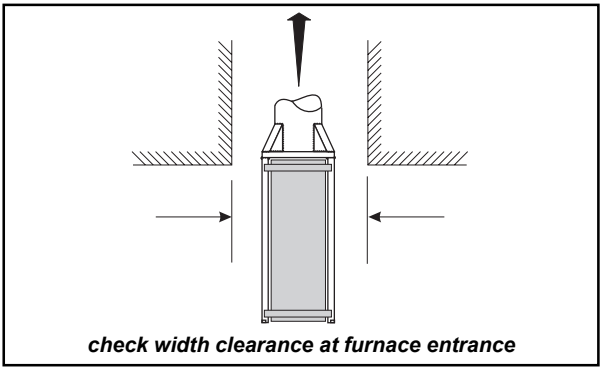


Diagram K

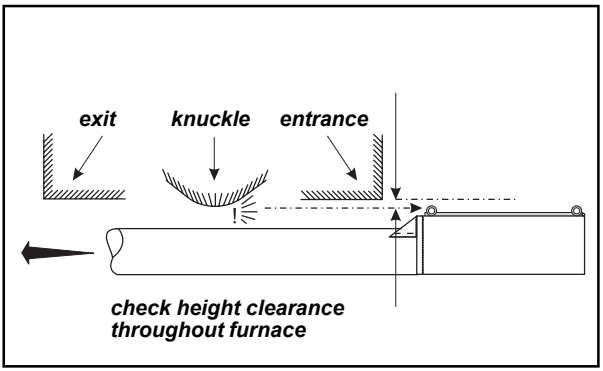


Diagram L

Setting up the Furnace Tracker system for the trial

Please refer to the *Tpaq21 Data Logger User Manual* for details of resetting the Tpaq21 logger and for use of the Insight software in connection with this.

After the billet and supporting forks have been prepared, and the Datapaq equipment unpacked and checked, the first operation is to set the thermocouples into the billet.

The lengths will need to be marked on a label attached to each thermocouple and this length will be specific to the points being measured. They should not be mixed up. Test each thermocouple by connecting it to the hand held thermometer (supplied) and heating the tip with an open flame. The thermometer should show an increase in temperature, if it does not, or shows signs of being open circuit, replace the thermocouple.

After testing, the thermocouple should be straightened enough to allow it to be pushed fully to the bottom of the hole in the thermocouple bush. See ***Diagram J*** for details of the thermocouple bushes.

NOTE ***Ensure that the holes in the billet for the thermocouples are free of any fragments from the machining operation.***

Placing the thermocouples – method 1

If the thermocouples are set in a machined slot along the length of the test billet (to protect from the direct heat of the furnace) proceed as follows:

Feed the thermocouples through the slot in the rear plate of the fork. This slot should directly align with the grooved machined along the length of the billet to take the thermocouples (see ***Photograph 3***).

Starting with the measuring position furthest from the thermal barrier,

insert the thermocouple into the thermocouple bush and measure the depth of insertion to ensure it is correct. Gently bend the thermocouple through 90° where it exits the hole (ensuring that a 10-mm bending radius is not exceeded), and carefully lead it along the slot (see ***Photograph 1***). Repeat this for all other thermocouples. As the thermocouples are positioned in this slot, set the steel blocks into position over them, working backwards from the further measuring position towards the thermal barrier (see ***Photograph 2***).

As each thermocouple is positioned in the bush, the high temperature plastic plug at the end of the thermocouple should be numbered (from 1 to 8, or 1 to 10, etc.). This will allow easy identification when all the steel blocks are in position (see ***Photograph 10***). Each numbered plug will need to correspond to its specific channel in the data logger (the channel numbers are marked on the Tpaq21 data logger). Keep a written note of which thermocouple has been connected to which channel.

When all the steel blocks have been laid and are flush with the billet surface, the thermocouples should be tested again to make sure that none were damaged when fitting, this is unlikely, but worth checking. When this is done the blocks should be tack welded to the billet. A tack weld 12.5 mm (0.5”) long on each side of the block is enough, as it will be necessary to remove the weld after the trial, so the billet can be reused if required.

Placing the thermocouples – method 2

If the thermocouples are secured along the outer surface of the test billet proceed as follows:

Test each thermocouple as described above. After testing, the thermocouple should be straightened enough to allow it to be pushed fully to the bottom of the hole in the thermocouple bush. Check that the required depth has been reached.

Gently bend the thermocouple through 90° where it exits the bush (ensuring that a 10 mm bending radius is not exceeded), and carefully lead it along the top surface of the billet (see ***Photograph 4***). As each thermocouple is positioned in the bush, the high temperature plastic plug at the end of the thermocouple should be numbered (from 1 to 8, or 1 to 10, etc.). This will allow easy identification when all the steel blocks are in position (see ***Photograph 10***). Each numbered plug will need to correspond to its specific channel in the data logger (the channel numbers

are marked on the Tpaq21 data logger). Keep a written note of which thermocouple has been connected to which channel.

Repeat this for any other thermocouples and secure them to the top of the billet with nickel or other high temperature wire. Work backwards from the furthest measuring position towards the evaporative thermal barrier securing the thermocouples at intervals of 400 mm (16”) with nickel wire.

When the thermocouples have been secured along the length of the billet, “tack” weld an inverted piece of angle iron the length of the thermocouples to protect them during transportation (***Diagram M***).

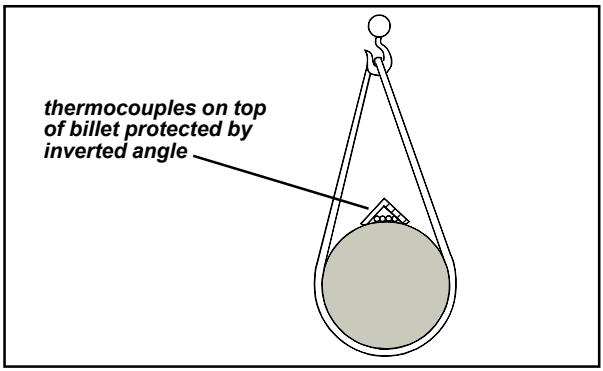


Diagram M

Where the thermocouples meet the fork that supports the evaporative thermal barrier, carefully bend them around the top of the fork and secure them temporarily until the evaporative thermal barrier has been placed in the fork (see ***Photograph 22***).

Clamping the thermocouples

When all of the thermocouples have been positioned at the correct measuring points and secured to the billet, they can be clamped using the thermocouple control clamp supplied. Clamping the thermocouples together makes it easy to plug them into data logger without the inherent “springiness” of the MI thermocouples working against you.

Starting with thermocouple no.1 straighten out the last 500 mm of MI thermocouple sheath beneath the PTFE tail (***Diagram D***). Mark a line 200 mm below the pot seal and slide the thermocouple into position 1 on the control clamp (see ***Photograph 12***). Tighten the screw on the side of the clamp to lock the thermocouple in position.

Repeat this for thermocouple no. 2, then 3, until all thermocouples are latched together in the clamp (see ***Photograph 13***).

Preparing the evaporative thermal barrier

The inner insulation layers and evaporative water jacket should now be positioned in the insulation cage.

NOTE ***When working with alumina fibre blanket, protective clothing such as gloves, overalls, approved dust mask, goggles, should be worn to prevent any skin irritation etc.***

A set of pre-cut insulation panels is initially supplied with the system. When these have been used, the templates supplied can be used as guides to cut new insulation panels from rolls of alumina fibre blanket. Locally purchased alumina fibre blanket can be used, ensure this conforms to the specification on p. 2. Refer to ***Photographs 5–9***.

NOTE ***The number of insulation panels (see below) varies between thermal barriers. The table below shows some typical barriers and the number of insulation panels employed; for other barriers, contact Datapaq.***

Number of insulation panels on each side, top and base of billet reheat thermal barriers.

	Thermal barrier no.				
	TB4066	**TB4102**	**TB4113**	**TB4127**	**TB4203**
Barrier height	250	300	230	360	250
Barrier width	250	300	300	450	350
Barrier length	550	600	550	590	670
No. of panels	2	3	2	2	2

Place the lower insulation panels supplied with the system into the bottom of the insulation cage. Then install the right- and left-side and

rear insulation panels into the cage. The evaporative thermal barrier can now be installed. Placing some thin cardboard each side of the barrier can make installation easier, the cardboard allows the evaporative thermal barrier to slide down easily into the insulation and must be discarded after fitting the barrier.

At this point fill the evaporative water jacket with tap water to the top of the filling tubes (see ***Photograph 19***).

WARNING ***Forgetting to do this will result in disaster!***

When the water jacket is full, position the top inner insulation panels into the insulation cage. Then secure the hinged top of the cage with nickel wire (see ***Photograph 20***).

The Datapaq Tpaq21 data logger can now be loaded into the water jacket. Firstly the logger must be reset; see the *Tpaq21 Data Logger User Manual*.

The numbered thermocouples should be plugged into the corresponding sockets in the Tpaq21 logger (see ***Photograph 11***). When this is complete slide the data logger to the rear of the main water jacket (see ***Photograph 14***) and carefully slide the logger protection cover into position over the thermocouples (see ***Photographs 15–16***). This will hold the thermocouples tightly in place.

NOTE ***The pots seals of the thermocouples will now be inside the evaporative water jacket.***

When the logger protection cover has been fitted into the evaporative thermal barrier, the control clamp can be removed from the thermocouples (see ***Photographs 17–18***).

WARNING ***Always remove the thermocouple control clamp before the test billet enters the furnace.***

Insert the rear insulation panels to shield the logger protection cover. It may be necessary to trim these panels in places to fit over handles etc. When the insulation panels are in place, the rear hinged door of the insulation cage can be secured with nickel wire (***Photograph 21***).

Carefully loop the excess thermocouple wire and fold it so it fits between the side of the fork and the insulation cage, or tie it to the top of the insulation cage (***Photograph 24***).

If there is sufficient clearance within the furnace, fit a further protective layer of insulation around the forks and system. Unroll the

alumina fibre blanket insulation (supplied) and cut a length sufficient to go completely around the barrier and fork, and overlap once at the top or side. Secure this outer layer of insulation with nickel or other high temperature wire (***Photograph 25***).

The test billet and system is now ready to go into the furnace (***Photograph 26***).

WARNING ***Never exceed the specified duration for your thermal barrier. This is shown on the barrier data sheet; if it is a special thermal barrier with no data sheet, refer to your original quotation. In case of any doubt about the thermal duration of your barrier, contact Datapaq.***

The time component of the thermal duration is a cold-to-cold time* (*e.g. 6 hours at 500°C/932°F etc.*): *from the logger entering the furnace to its removal at the end of the process. It is important to adhere to the specified barrier duration as the data logger used may contain non-rechargeable lithium batteries, which – if exposed to temperatures above 250°C/482°F – are at serious risk of bursting explosively. If the thermal duration of the barrier is exceeded, and the cooling water runs dry, the logger will quickly exceed this critical temperature. Should this happen, the thermal barrier may contain the explosion but the logger and the interior of the thermal barrier will be irreparably damaged.

Charging and discharging the test billet in the furnace

This is the most difficult part of the operation and will need to be thought through carefully and if possible practised before carrying out a trial. A practice run is strongly recommended using a test billet with the fork welded to it. The Datapaq system and thermocouples should not be used at this stage. This trial run will uncover many small difficulties in the charging and discharging operation that need to be overcome before a full trial using the Datapaq system is attempted.

These are the main points to check:

Rotary hearth furnace

Keep the system level while getting the test billet to the charger (to avoid spilling the water in the evaporative thermal barrier).

If there are “star wheels” in the loading mechanism, and these cannot be bypassed, then load the system into the fork on the test billet after it has travelled past the wheels and is positioned below the charger (the star wheels turn the billet through 180°).

Check the height and width of the entrance and exit to the furnace, and the clearance above the evaporative thermal barrier in every zone.

Check there is adequate space to remove the data logger and system when the test billet exits the furnace.

Check that the test billet and fork can be safely moved away from the production line once the system has been removed.

If the charger will not clear the Datapaq system as it places it in the furnace, then load the test billet so the system enters the furnace first (***Diagram N***).

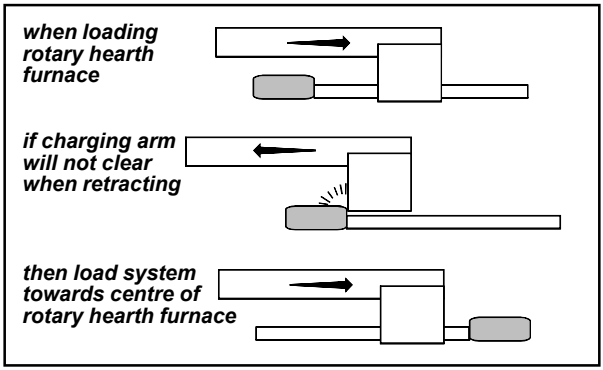


Diagram N

Pusher and walking beam furnace

Check there is adequate clearance in the entrance and exit of the furnace for the test billet and system to pass through (***Diagrams K and L***).

Check that there is adequate clearance above the system in every zone in the furnace. (***Diagram L***).

Check that the clearance between billets can be maintained and still have enough space for the Datapaq system on the test billet. This may necessitate shortening the billet preceding the test billet, and the billet following the test billet (***Diagram F***).

Check that the system can be removed from the test billet before the billet enters the pinch rolls, or that the test billet can bypass the pinch rolls (***Diagrams O and P***).

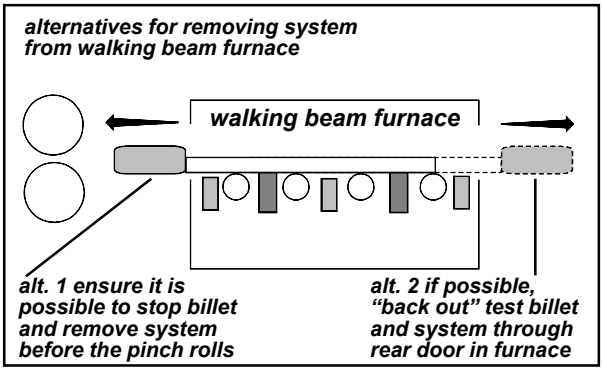


Diagram O

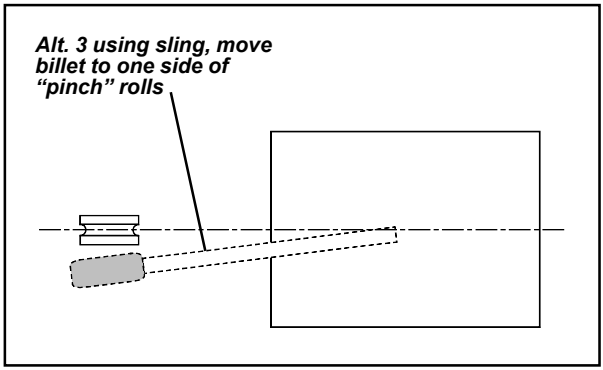


Diagram P

Removing the Tpaq21 data logger after a run

It is best to remove the Tpaq21 data logger as soon as the billet has exited the furnace. The billet should be situated in an area where the system can be accessed easily. The reason for removing the data logger quickly is that if the billet is left to cool down before removal, the remaining water in the main water jacket may boil off completely. This will increase the external temperature of the Furnace Tracker evaporative thermal barrier to a level beyond it's specification and may cause damage to the data logger.

Removing the data logger from the evaporative thermal barrier is not a difficult operation but extreme caution should be taken, as the billet will be at maximum temperature.

WARNING ***Heat-protective clothing and an approved dust mask must be worn; see 'Equipment required' (above).***

After exiting the furnace, transport the test billet to a safe area where the insulated system can easily be accessed. If this is not possible to do, for example in the case of a rotary hearth furnace, it may be possible to remove the data logger and system when the test billet is held beneath the discharging arm (***Photograph 28***).

Cut a piece of alumina fibre blanket approximately 1.5 meters long and place this onto the billet as shown in ***Diagram Q***. This will cut down the heat output from the billet and leave a working area to remove the data logger.

Open the rear hinged door on the insulation retaining cage and remove the insulation panel covering the logger protection cover. Slowly remove the logger protection cover and place this on the floor away from you.

Pull out the thermocouples. This will draw the data logger out of the evaporative thermal barrier. Grasp the logger and quickly remove it from the evaporative thermal barrier, then disconnect the thermocouple plugs and remove the Tpaq21 data logger completely.

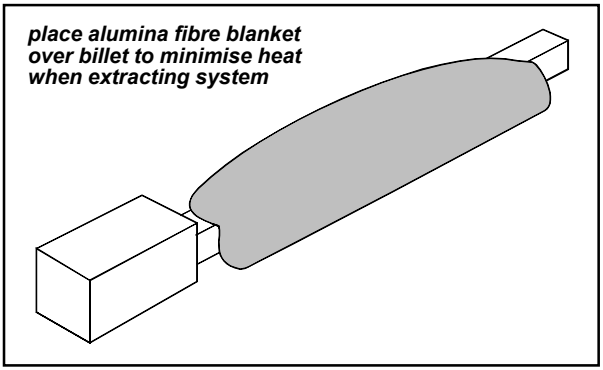


Diagram Q

NOTE ***If the plugs are difficult to remove then cut the PTFE tails and remove the plugs at a later stage. Do not worry about cutting the PTFE tails, as the thermocouples will not be used more than once.***

When the Tpaq21 logger has been taken away from the hot billet, the stored data can be downloaded to the computer; see the *Tpaq21 Data Logger User Manual*.

Removing the Furnace Tracker system from the billet

NOTE ***When working with alumina fibre blanket, protective clothing such as gloves, overalls, approved dust musk and goggles should be worn to prevent any skin irritation.***

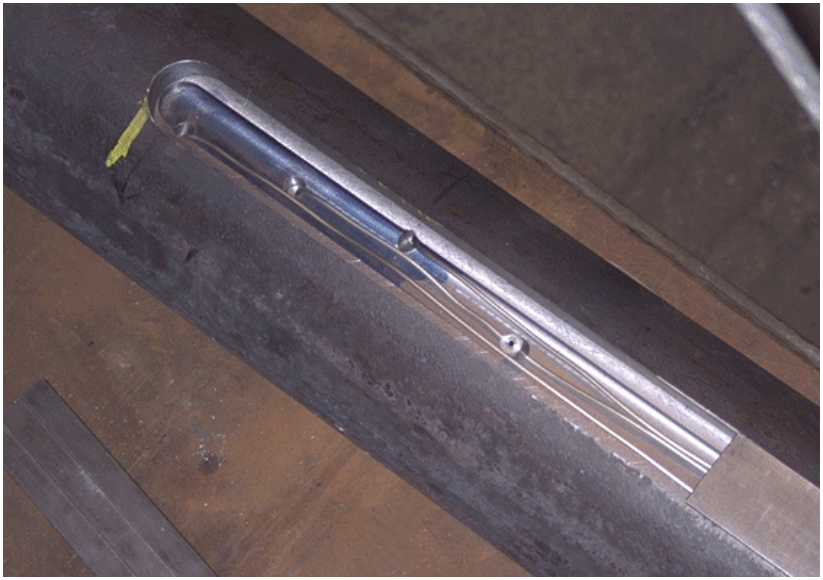
When the test billet is cool, the insulation cage and evaporative thermal barrier can be removed.

Strip back the outer layers of insulation and remove the insulation cage and the system. There may be some distortion of the insulation cage due to the heat, but this should not cause a problem unless the distortion is severe. If this is the case then the frame can be carefully straightened, but care should be taken not to damage the welds. The remaining insulation should be placed in sealed polythene bags and disposed of in a manner that adheres to local waste disposal rules.

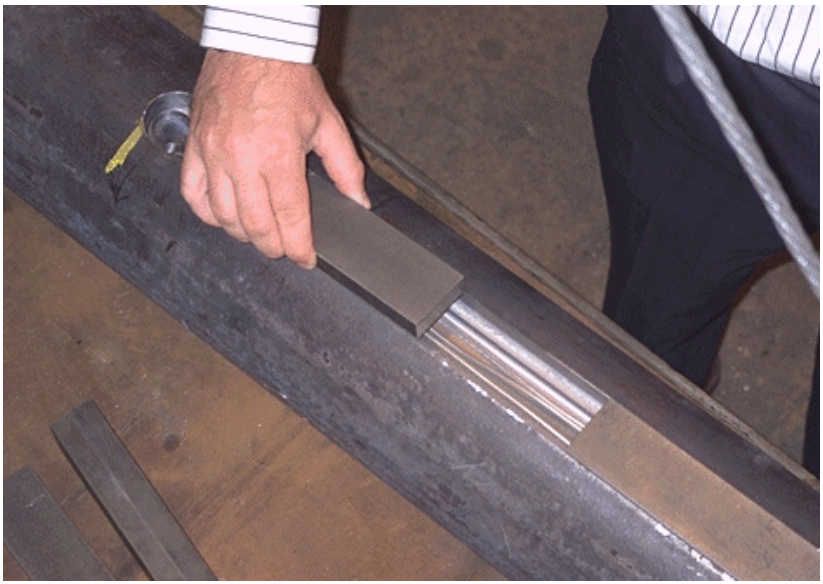
If the billet has been machined to protect the thermocouples against the direct heat of the furnace, then the tack welds can then be lifted from the blocks and the blocks removed and reused. The thermocouples should be discarded as there is no guarantee that they will survive another run and give accurate results.

It is also possible to carefully remove the system from the billet directly after it has exited from the furnace. This can be achieved by using the special hooks provided with the system to hook into the eyes in the insulation cage. Alternatively two lengths of 12.5-mm diameter (1/2”) steel bar can be inserted into the top cage supports and the whole system lifted clear (***Photograph 29***). Ensure the data logger has been removed, or the thermocouples cut before attempting this.

Photographs 5–21 which follow show in principle how to set up the Furnace Tracker system. Photographs 1–4 and 22–29 show how this is achieved in an actual application.

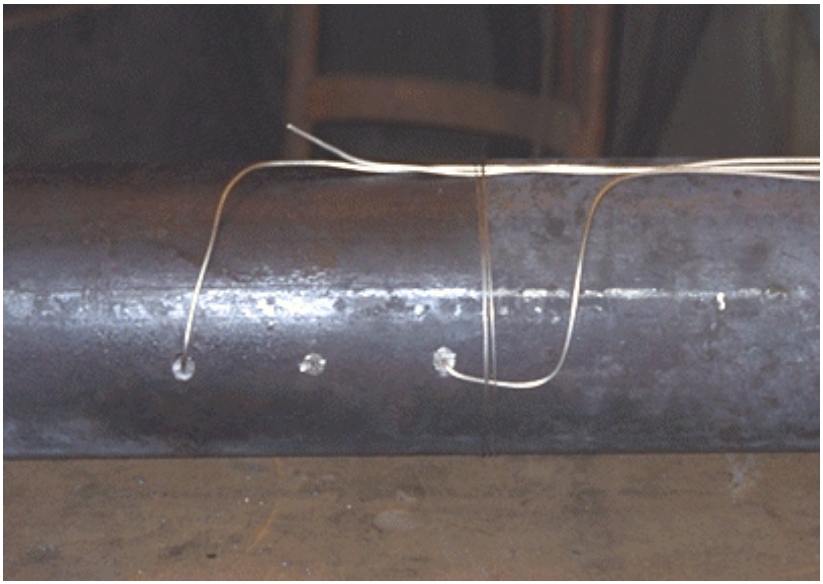


Photograph 1
Method 1: thermocouples are led along the longitudinal slot



Photograph 2
Method 1: steel blocks are placed over the thermocouples

Photograph 3
Method 1: thermocouples pass directly from the slot through the back plate of the fork



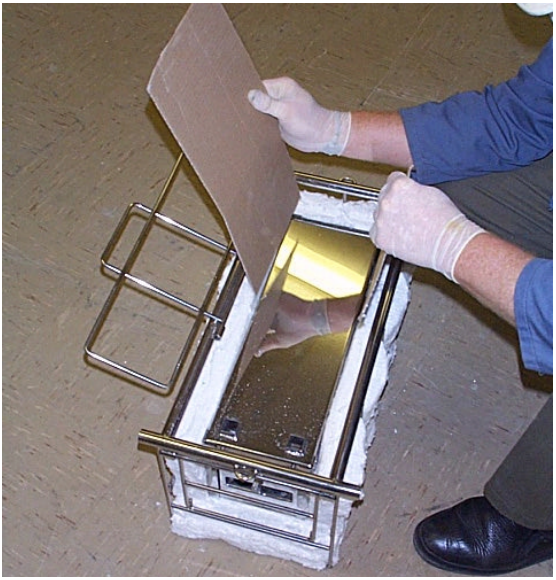
Photograph 4
Method 2: thermocouples are secured to the top of the billet with nickel wire

Photograph 5
From the inner insulation set, place the lower insulation panels of alumina blanket at the base of the cage (see p. 20 for number of panels to use)

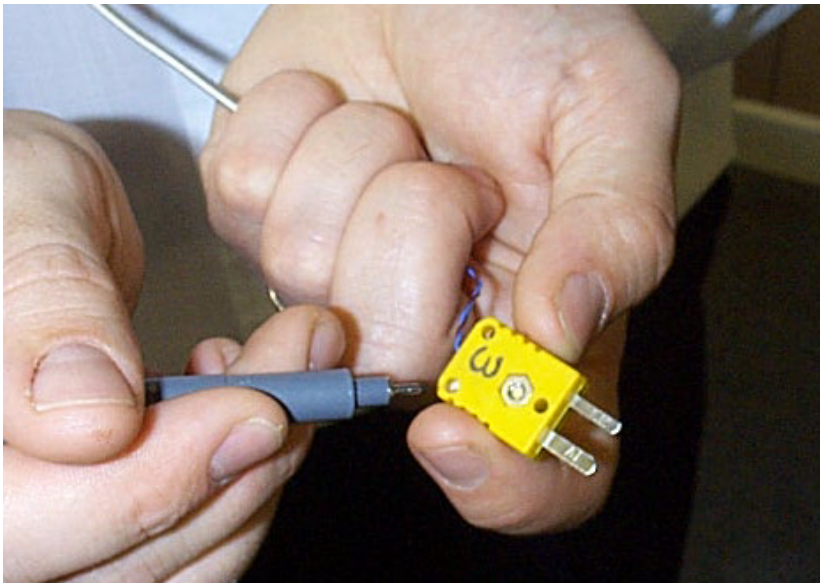
Photograph 6
From the inner insulation set, place the side insulation panels of alumina blanket at the rear, left and right sides of the cage (see p. 20 for number of panels to use)

Photograph 7
Place 2 pieces of cardboard on the inside face of the insulation panels to help install the evaporative water barrier

Photograph 8
Fit the evaporative water barrier in the centre of the cage

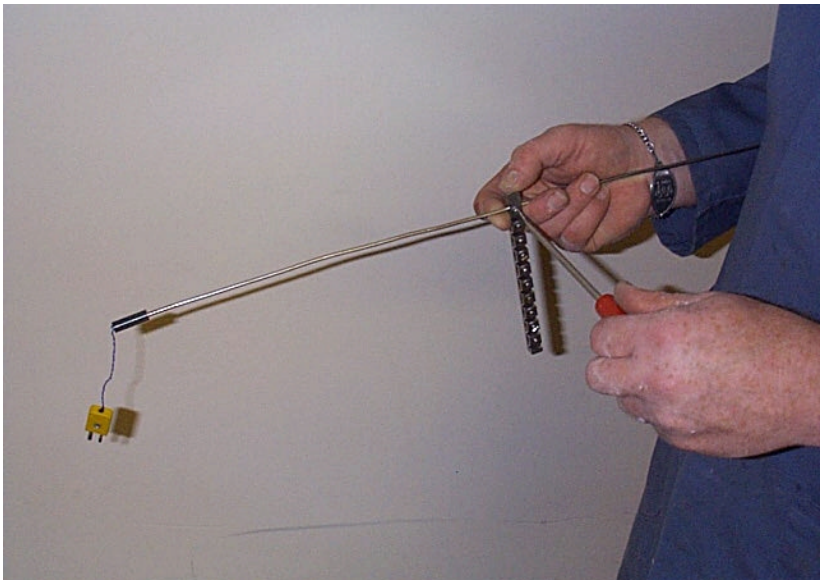


Photograph 9
Remove the cardboard panels

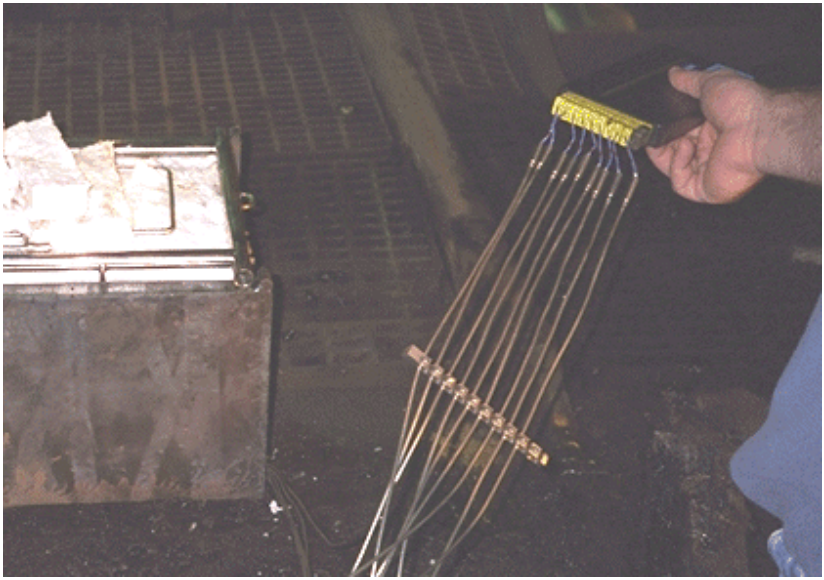


Photograph 10
Marking the thermocouple plug with the corresponding channel number

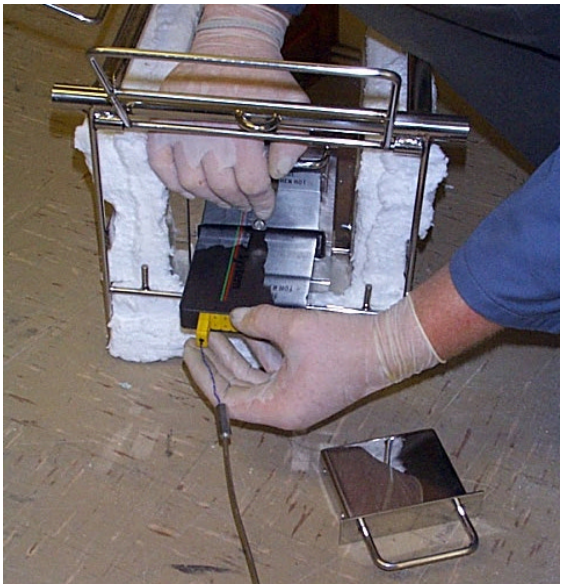
Photograph 11
Plug the correct thermocouple into the numbered socket on the data logger



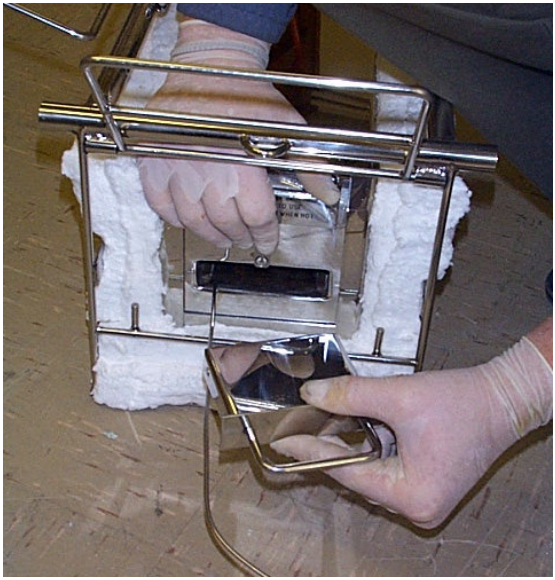
Photograph 12
Straighten the thermocouple and fit the clamp 200 mm (8”) from the plug



Photograph 13
The thermocouple control clamp holding the thermocouples in position

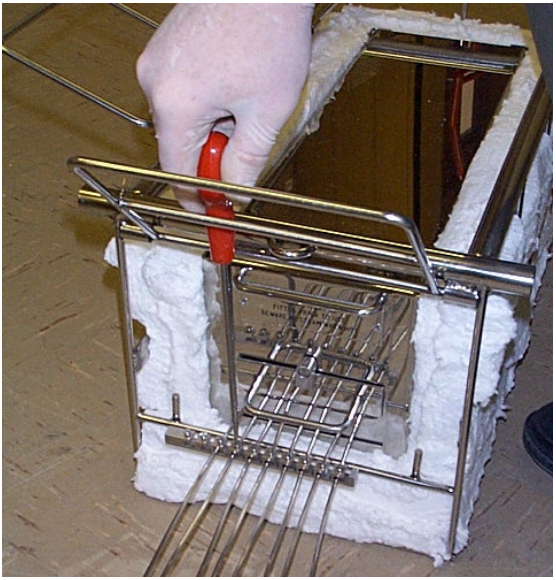


Photograph 14
Hold the retaining catch in an upright position and slide the logger fully into the evaporative water jacket



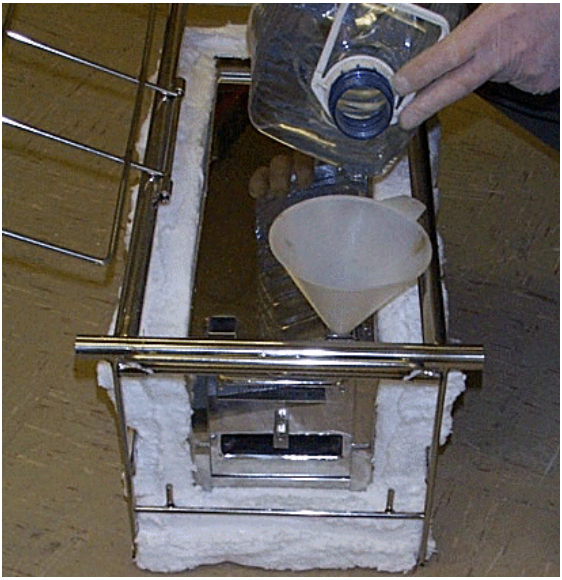
Photograph 15
Fitting the logger protection cover over the thermocouples

Photograph 16
The logger protection cover holds all the thermocouples in place. Note: the control clamp holds the thermocouples securely while the logger is placed in the thermal barrier



Photograph 17
After fitting the data logger and logger protection cover, loosen the screws on the thermocouple control clamp

Photograph 18
Remove the thermocouple control clamp before placing the test billet into the furnace

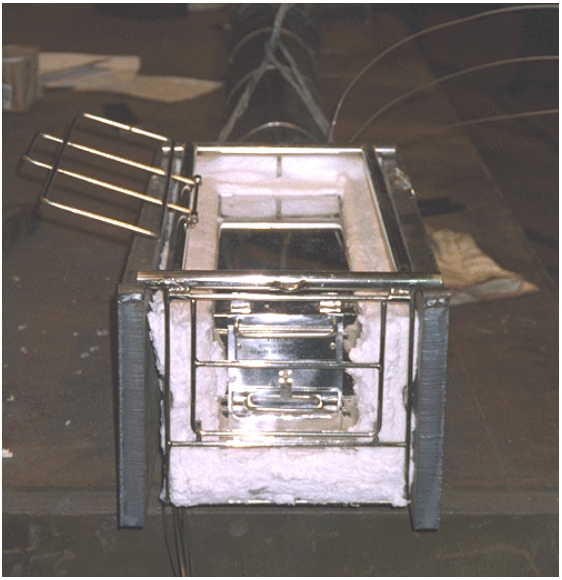


Photograph 19
Filling the evaporative jacket with water

Photograph 20
Fit the top insulation panels and secure the hinged lid with nickel wire

Photograph 21
Fit rear insulation panels and secure the hinged door with nickel wire

Photograph 22
The thermal protection barrier waits to go into the supporting forks. Note: the thermocouples are secured to the billet by nickel wire and are taken across the top of the forks (background)



Photograph 23
The water jacket and insulation cage positioned in the fork

Photograph 24
Excess thermocouple length is looped and secured on top of the system

Photograph 25
The final insulation layer is secured with nickel wire

Photograph 26
The system, secured to the test billet is held beneath the charging arm

Photograph 27
The test billet exits the furnace

Photograph 28
The Tpaq21 and system are removed from the billet

Photograph 29
Rods inserted into the barrier are used to lift it from the fork

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