MODEL 970-1 & 970-2 CALIBRATION FURNACE INSTRUCTION MANUAL

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MODEL 970-1 & 970-2

CALIBRATION FURNACE

1200 Deg.C. Three Zone

Horizontal Tube

Temperature Calibration Furnace

Instruction Manual

CONTENTS

1.Warranty

This instrument has been manufactured and tested in accordance with the manufacturer's specification and quality control procedures. It was inspected & tested to safety standards for electrical insulation, earth impedance and is fully compliant with electrical safety class 1, under IEC 1010-1.

This instrument is guaranteed for 12 months against electrical and mechanical breakdown caused through defective materials or workmanship providing correct operation and safety procedures have been used. In addition correct electrical and mechanical installation has been performed to avoid personal injury or fire from high temperature operation (100 to 1200deg.C.) using recommended health and safety features (refer to Section 5).

Any mechanical or electrical failure caused from miss-use or by not using recommended safety features will not be covered.

In the event of failure covered by this guarantee, the instrument must be returned to the supplier for examination and will be repaired or replaced at our discretion and returned at our cost.

2. Operational Safety

Personnel using this equipment must be trained in its use and good measurement practice. It is essential personnel understand the hazards of this equipment when operating at high temperatures (100 to 1200 deg.C.) and precautions needed in its use. Refer to safety features section 13 and the Health and Safety instructions section 3.

3. Health and Safety Instructions

(1) This manual must be read completely.

(2) This product must be electrically and mechanically installed correctly as detailed in this manual with correct safety features being used (section 3 &13)

(3) Safety notices warning of high temperature must be clearly visible and any necessary barriers installed to prevent accidental touching / burns by laboratory/operational staff when operating at high temperatures above 300 deg.C.

(4) Operators must wear appropriate protective clothing as detailed under Safety Section 13.

(5) Operators must be suitably trained in the use and handling of high temperature items.

(6) Do not dismantle or open/work inside this equipment without first isolating it from the electrical supply and allowing it to cool to ambient temperature.

(7) Do not operate this product outside its recommended temperature ranges in the specification.

(8) Ensure any other materials are kept away from the hot parts of this furnace, especially when operating to maximum temperature to prevent the risk of fire.
e.g. liquids or oils reaching their flash/automatic flammability point.

(9) Other local plant/laboratory health and safety instructions / regulations must be operated.

4. Product Description

The 970 furnace series provides a 3zone electrically heated, horizontal tube furnace as illustrated in Appendix 1. The heated length is divided into 3 zones each with its own temperature controller, power regulator to the heater winding and a thermocouple temperature sensor. The power supplied to the end zones is automatically adjusted to compensate for the heat loss occurring at either ends of the central tube, using a “Master-Slave” configuration with the centre zone control in order to maintain all 3 zones at a uniform temperature. This system provides a much longer uniform horizontal temperature zone than other systems, e.g. single zone vertical or horizontal furnaces. Also adjustment of the end zone controllers at some points over the wide furnace operating range (100 to 1200 deg.C.) enables the variable losses at the furnace ends to be corrected (extra power to correct for insulation losses and different operating loads such as number and size of sensors being calibrated). This provides a similar “flat” uniform zone at any set point control temperature over 100 to 1200 deg.C. to within better than 0.2 deg.C over a 200mm central furnace length using a suitable metal equalizing block in the central work tube. The “radial” uniformity is obtained by the concentric even furnace winding around the outer diameter of the main furnace tube. This enables uniform radial temperatures for a series of holes on a common P.C.D. (pitch circle diameter) using a centrally placed equalizing block in the centre tube.

This 970 furnace is provided in 2 main versions:-

(1) Model 970-2 with a centre main work tube of 3.15ins. (80mm.) internal diameter

When using the main 80mm. i.d. furnace tube a large (up to 3in. diameter) metal equalizing block can be used allowing for a large number and variety of probe sizes to be accommodated. This also allows probes with larger “head” diameters / shapes to be fitted in addition to short probe length designs.

When very short probes are calibrated, the metal equalizing block can be moved closer to one end of the furnace. With the use of the 80mm. main centre work tube only, the insulated separately spaced outer furnace end plates can be removed, to allow larger and shorter access to the inside work tube and larger equalizing block to 3ins. Diameter.

(2) Model 970-1. This uses an additional centre work tube within the main tube. This tube is supported by the insulated separate outer end furnace plates shown. This provides improved horizontal heat uniformity along the furnace length. Also complete electrical isolation is provided at higher temperatures (600 deg.C. and above) for the metal equalizing block and probes tested from the heater windings / outer main furnace tubes. This prevents small spurious voltage input when using very sensitive digital voltmeters for more precise primary standard thermocouple calibrations by comparison calibration techniques.

This separate centre work tube is normally 2.55ins. internal diameter (65mm) and can be used with metal equalizing blocks up to 2.3 ins. Diameter (58mm) for mounting probes to calibrate. This smaller diameter / area work tube maintains a lower horizontal uniformity over the temperature range using a metal equalizing block of 200 to 250mm.length.

This separate work tube is easily replaced compared to the main outer work tube which is wound with the heater windings. This also enables a range of smaller work tube diameters to be easily fitted by simply changing the 2 insulated outer end plates and metal covers. These insulated and separately spaced outer end plates from the main furnace provide an additional “heat barrier” at the hot furnace ends when temperatures above 600 deg.C. are used.

8. Product Features

(1) Wide temperature range (100 to 1200 deg.C).

(2) High stability and low thermal gradient temperature source for calibration by comparison.

(3) For use with wide range of sensors including large metal sheathed sizes to over 0.75 ins. diameter and facility to calibrate short sensors.

(4) Large immersion depths and low immersion depth errors.

(5) Probe immersions up to 22 ins. from one side.

(6) Probe immersion / calibration from both ends of furnace, doubles calibration volume and throughput.

(7) Wide range of replaceable internal furnace tube diameters from fixed 3.15 in. diameter (80 mm) to 2.55 / 0.5 in. (65 to 12.5 mm.) replaceable tube range.

(8) No moving parts / high reliability.

(9) Automatic 3 zone temperature control with individual adjustment of end zone power over temperature range to compensate for losses and provide very low horizontal temperature uniformity errors.

(10) Over-temperature “alarm cut-out’.

(11) Maximum power limit facility on all zones.

(12) Controlled ramp rate setting to provide temperature rise limit (deg.C. / min.).

(13) Three phase or single phase operation on supply lines.

(14) Input power circuit breaker with overload cut-out.

(15) Three pole isolation contactor to furnace heater zones.

(16) AUTOMATIC CALIBRATION- When furnace used with TTI7 or DVM / scanner and TTI7 E software a fully automatic, large capacity, thermocouple calibration system can be operated overnight using 10 to 24 TC channels with 3 or more sets of TC channel data at 3 to 15 or more pre-set temperature points with automatic report writing.

6.Product Specifications

		Model 970-2	Model 970-1
(1) Temperature Range	: deg.C.	100 to 1200	100 to 1200
	: deg.F.	200 to 2190	200 to 2190
(2) Temperature Stability	:100 to 800 deg.C. within :-	0.1 deg.C.	0.05 deg.C.
	200 to 1500 deg.F. within :-	0.18deg.F.	0.09 deg.F.
	800 to 1200 deg.C. within:-	0.2 deg.C.	0.10 deg.C.
	1500 to 2190 deg.F. within:-	0.35deg.F.	0.18 deg.F.
(3) Temperature Uniformity : (using metal block)			
Horizontally	: 100 to 800 deg.C. within:-	0.1 over 6 ins.	0.05 over 8ins
	200 to 1500 deg.F. within:-	0.18over 6ins.	0.09 over 8ins
	800 to 1200 deg.C. within:-	0.2 over 6 ins.	0.10 over 8ins
	1500 to 2190 deg.F. within:-	0.35over 6 ins.	0.18 over8ins.
Radially	: 100 to 800 deg.C. within:-	0.1 deg.C.	0.05 deg.C.
	200 to 1500 deg.F. within:-	0.18deg.F.	0.09 deg.F.
	800 to 1200 deg.C. within:-	0.2 deg.C.	0.10 deg.C.
	1500 to 2190 deg.F. within:-	0.35deg.F.	0.18 deg.F.
(4) Internal work tube diameter :-		3.15ins.Fixed (80 mm.)	3.15ins.Fixed & 2.55ins. or 2.55 to 0.5ins. as specified. (80mm / 65mm to 12.5mm)
(5) Electrical Heaters (110 V. AC.)	1 x Centre Zone :-	1.5 kW.8.1ohm	1.5kW.8.1ohm
	2 x End Zone,each	1.75kW7.9ohm	1.75kW7.9ohm
(6) Electrical Supply		3 phase (star) 110 V. / phase 2x16A.+1x13A Total 5.0 kW. OR 1 phase 110 V. 5.0 kW. 45 A.	3 phase (star) 110 V. / phase 2x16A.+1x13A Total 5.0 kW. OR 1 phase 110 V. 5.0 kW.45 A.
(7) Overall dimensions (Length x Height x Depth)	ins.	32 x 21.5 x 12	32 x 21.5 x 12
	mm.	813x533x305	813x533x305

	Model 970 – 2 and 970 – 1
(8) Temperature control :-	Centre zone master controller with input range 0 to 1200 degC. 2 x end zone “slave” controllers with input differential range of +/- 7 mV. (+/-200 deg.C.)
(9) Over temperature trip controller :-	0 to 1200 deg.C. range to 1 deg. C.resolution with relay closure output on overtemp.
(10) Control / measurement thermometers :-	Centre zone : 4 x N type TC 1- centre zone control 2- end zone control differential 1- independent overtemp. alarm & front socket indication.) End Zone: 2 x N type TC -1 in each end zone centre for end zone differential control. 2 x separate end zone indication TC’s on front panel positioned 2.1 ins.(53mm.) from inside each end of outer end zone winding at 3.0 ins (75 mm.) inside outer end of main furnace body.
(11) Electrical isolation & safety :-	Supply input , 2 pole isolation circuit breaker and over current protection trip for single phase or 3 pole for 3 phase. 3 pole latching isolation relay to heater power regulators / heaters with main latching furnace power ON and OFF indicator push button switches linked to independent over temp TC alarm to isolate heater power via 3 pole heater power relay

7. Theory of Operation

Furnace Control

As illustrated in Appendix 1 the 970-1 and 970-2 horizontal tube furnaces are divided into 3 heated zones, each with its own temperature controller and thermocouple for measuring and control. The centre zone operates independently as the "master" control to maintain the furnace centre at its desired set point control value. The two end zones are operated in a "master – slave" configuration with the temperature input to the end zone controllers being the difference between the centre zone TC and the end zone TC. As the centre zone temperature rises the differential input voltage / temperature raises the temperature of the end zone. The end zones automatically track the centre zone temperature in order to maintain a constant temperature and horizontal profile.

The power to the outer end zones is automatically adjusted to compensate for heat loss changes at the ends of the furnace. In order to compensate for variable heat losses occurring at the furnace ends over its wide operating temperature range and with the variable "load" conditions (small / large thermometer diameters and the quantity and type of probes inserted for calibration) the differential "Set-Point" input controls on the end zone controllers are used to increase or decrease an "offset" control voltage. This will raise or lower the end zone temperature to obtain a "flat" uniform temperature over the furnace length.

Equalization Blocks

To provide a constant temperature zone for probes being calibrated with improved uniformity and short term stability, metal equalization blocks can be fitted to the furnace tube with suitable close fitting holes (0.015 / 0.02 ins. – 0.4 / 0.5 mm. clearance). Refer to examples in Appendix 3 and 4 for the 970-2 furnace. This will also improve immersion errors as detailed in Appendix 8 – thermometry uncertainty report TU 2.

Calibration Capacity

The advantage of this type of furnace is that probes can be loaded from each end of the furnace into holes drilled into each end of any equalization block. This doubles the probe calibration capacity for each calibration program of multiple temperature points. Refer to the furnace operation and calibration instructions and calibration performance optimization Sections 13 and 14 for detailed use and operating positions of the equalization block.

Electrical

As illustrated in the electrical diagram under Appendix 2, the supply input is connected to an independent circuit breaker (combined switch and overload current trip) This provides both over-current and short circuit protection with complete electrical isolation of the furnace and electrical controls / instrumentation.

The operating supply input can be 3 phase 110 V. per phase at 16 amps for the end zone and 13.5 amps for the centre zone. This is fed through a 3 pole latching 20 A. per line isolation relay to each of the 3 furnace heater zones via the series “regulator” (solid state control relay). This allows the 5 kW. total load during maximum heating power to be divided onto the 3 phase supply (1 heater zone per phase).

As shown, an alternative single phase supply at 110 V. 5kW.(42 amps) can be used by connecting the input 3 phase terminals in parallel . This single phase supply is fed via the same 3 pole latching relay to the 3 furnace heater zones.

A separate fused (3A) supply from the main terminals after the input supply circuit breaker feeds a distribution bus-bar for the local control equipment (controllers, relays, indicators).

A furnace power ON button with green ON lamp operates the 3 pole latching 20 amp. per line isolation relay RL2 to the 3 separate furnace zone heaters and solid state control relays.

A separate furnace power OFF button with red indicator lamp switches off the 3 pole isolation relay supply to the 3 zone heaters and solid state relays to isolate main power to the furnace, while leaving the temperature controllers operating.

Over temperature alarm and “cutout”

An entirely independent TC on the centre zone and an over temperature controller on the front panel can be set to provide an “alarm” in the event of the furnace temperature exceeding a pre-set high limit. The alarm controller closes a set of output contacts which operates a separate control relay RL1 to trip the main furnace 3 pole relay RL2 to isolate power to the furnace, switching on the red front panel over-temperature indicator. This protects the furnace if any fault causes permanent full power to be applied which would cause over-heating of the furnace and “burn-out” of the windings

8.Unpacking, Inspection and Assembly

Unpacking / Inspection

Visually check for any physical damage to the shipping container and carefully inspect the equipment area adjacent to any damaged packing.

Check there are no missing items from the delivery note. Inform supplier immediately of any missing items or damage. Retain all packing material in case of damage for inspection by Insurance assessor.

Furnace Assembly

970-1 furnace using separate internal work tube.

Unpack and insert tube carefully into centre of the main furnace tube, cleaning to remove any packing material or dust. Ensure main furnace work tube has no packing material particles, removing and cleaning inside of tube.

Using assembly instructions, position the 10mm. furnace end insulation plate into the metal end plate with 4 holes. Using the bolts/washers provided, attach furnace end plates to end of furnace over the protruding separate work tube from furnace end. The metal end plate/cap must be external to the furnace end. (Furnace end insulating plate is next to the main furnace end with a 10mm. gap). Repeat for the opposite end of furnace, so that the separate work tube sits in the centre of furnace, supported by the insulated end plates and metal end caps.

NOTE : A large plain metal washer is placed on end of the 4 bolt threads (next to insulated end plate) before offering and fixing the end plate assembly to the 4 tapped holes on the furnace ends.

Assemble the furnace control and electrical system unit to the tubular furnace, connecting the 2 flexible cable covers with the furnace thermocouple leads and heater supply cables to the control unit rear panel entrance glands.

970-2 furnace with internal fixed work tube only

Attach the 2 metal furnace end caps and 10mm insulated end plates using the 4 bolts as detailed above.

Assemble the furnace control and electrical system unit to the tubular furnace as above.

9. Furnace Installation.

Install on a solid, stable surface / bench with adequate space for ventilation (minimum 24 ins. on both sides and 40 ins. above furnace) Allow sufficient end space for loading maximum probe length with a minimum distance to any other instruments or wall of 30 ins. This allows heat generated from furnace at its maximum operating temperature to escape freely. Ensure no inflammable materials are used in mounting or close vicinity of furnace which could ignite in case of extreme catastrophic external damage to furnace at high operating temperatures.

10. Electrical Supplies / Connections.

Ensure local supply line, wall socket or break-out box is available for correct rating of supply to be used. (3 phase 190 V. 5 kW. – 110 V. per phase, star with neutral and earth / ground connection OR single phase 110 V. 5 kW. 42 amp)

Using 3-phase supply
Connect 3 phase star supply + neutral + ground (5 wire) cable rated at 20 amps per line with neutral and ground rated at 35 amps. from laboratory / plant supply box through furnace control unit cable entry to the 3 phase circuit breaker input, neutral bus-bar and ground (earth) connections in the furnace control unit.

If a 3 phase supply previously requested, a cable will be supplied and wired at factory from furnace control unit cable entry for connection to local supply box.

Using single phase supply.
Connect single phase (Line, Neutral and ground / earth) 3 wire cable rated at 50 amps per line from local supply box through furnace control unit cable entry. Connect 2 wire line and neutral leads to 2 inputs on circuit breaker and ground (earth) wire to earth bus-bar terminals.

If single phase supply not previously requested it is necessary to change input power connection in furnace control unit as follows :-

(A) Connect 3 "Line" supply terminals (R, Y, B on drawing appendix 2) together using the copper bus-bar strip provided.
(B) Disconnect L2 to Y lead and using 50 amp cable link provided, connect L2 to the Neutral 1, 2 and 3 bus-bar terminals.

11.Furnace Operation and Calibration.

Insert required metal equalization block into furnace work tube. Use large 3in. diameter metal blocks in the main outer work tube and smaller blocks (up to 2.55 ins. Diameter) in the separately mounted model 970-1 furnace tubes. The large 3 ins. Diameter blocks are used when large capacity calibration is required or for large head and short probe designs. For 3 in. diameter block design using ceramic tube insulators (refer to Appendix 5) ensure the block is mounted with ceramic tubes in lower half of block resting on the work tube.

Position block in the furnace to suit the probe length being calibrated. For long thermometers / standard probes, position block in centre of furnace (Appendix 5). For medium length probes (11 to 12 ins.) position block as shown in Appendix 6. For short or extra short probes (8 / 9.5 ins. or 4.5 / 5.5 ins.) position the block as illustrated close to one end of furnace.

Prepare thermocouples for calibration (refer to Section 2.2 Calibration Procedures CP10 manual) and insert into correct holes in block for close fitting (refer to Appendix 3 and 4). Connect thermocouples either directly to measuring instrument or via TC compensating wire. Connect reference thermocouple to instrument channel (AO or BO for TTI7 instrument) and position in metal block. Using high temperature continuously rated Kaowool to 1200 deg.C., insulate carefully the ends of the furnace to prevent heat losses particularly around air gaps where probes protrude.

Switch on laboratory supply to furnace.
Switch on the furnace control instrument circuit breaker, the instrument RED supply lamp is lit and main RED OFF lamp adjacent to furnace power off button illuminates. All 3 temperature controllers and over temperature control unit front panels are illuminated.

Set “Over-temp” controller “up – down” controls to 50 deg.C. above maximum calibration temperature to be used. Set centre “furnace control” unit to the first lowest calibration temperature on lower controller display using the up/down arrow keys.

Press furnace power ON green button on furnace control unit. The furnace will start to heat up and the upper furnace centre controller display will start to rise. The two end zone controllers will shortly indicate they are driving power to the furnace end zones after their differential input increases with rise in centre zone temperature. Their top left lamps will either flash almost continuously or remain permanently on.

For initial adjustment of end zone controller offsets to correct for end zone losses and improve horizontal temperature uniformity in the furnace and metal block, adjust up/down end zone controller arrow keys. For 300 deg.C initial temperature control adjust up keys for +0.4mV. on each end zone. For control to 500 deg.C set end zones to +0.6 mv.

Monitor the furnace temperature using the standard reference probe on the measuring instrument or plot as a graph using PC soft-ware. When final temperature stabilization is re ached the end zones should be in control with their control lamps blinking to indicate an average control power input to the furnace end zones.

Checking horizontal uniformity
The temperature uniformity from end to end of the furnace will vary depending upon the end zone losses. These vary with the temperature value, being much higher at 600 to 1200 deg.C. The total losses and end zone “temperature droop” will also be dependant on the end zone insulation and its packing density used, together with the size, type and number of probes inserted.

To check and adjust/trim the furnace end zone differential “offsets”, insert a long TC probe into the centre hole of the equalization block in furnace. It is assumed that the block has been mounted centrally between the furnace ends. While recording this probe in the centre position, slowly re-position it at l in. intervals and monitor the temperature change. Leave the probe at each position for approximately 5 mins. dependant on probe response time to achieve thermal equilibrium. The temperature profile over +/- 4 ins. from the centre of the block can be monitored. The end zone controller up/down keys can be adjusted to obtain the best uniformity.

The reference and probes under calibration can be scanned and monitored by an attached DVM/scanner or using the TTI7 digital thermometer / scanner system. Refer to Section 16 for automatic calibration and data logging under computer control.

12.Calibration Performance Optimization

The horizontal profile of the furnace should be carefully monitored over the length of any equalization blocks under the standard test conditions for the probes used and the end zone insulation. Short probes calibrated using the equalization blocks closer to the furnace end, will need more care to obtain the maximum insulation / lowest end loss with adjustment of the particular furnace end controller used to obtain the lowest gradient. When using the equalization block in the centre of the furnace with long probes, additional Kaowool insulation can be used at each end of the furnace to reduce heat loss and improve the gradient in conjunction with the end zone controller differential “offset adjustment”.

To establish radial uniformities use two identical size and thermal properties probe which closely fit (within 0.4 mm. approx.) 2 diagonally opposite holes A and B. Make comparison measurements in these two hole positions measuring test probe TP in position A and the reference probe RP in position B.
Error test probe TPE = 0.5 [(PosA. TP – Pos B.TS)+(Pos B.TP-Pos.A.TS)]

When mounting probes in metal block, holes used should be on the same P.C.D. for best radial uniformity.

It is important all probes use close fitting holes and are inserted to the same depth to reduce thermal immersion errors. In 3 zone horizontal tube furnaces with blocks mounted closer to the furnace centre immersion depth errors are considerably lower compared to alternative systems and designs because of the additional heat area in front of each probe or block before the furnace end and room temperature.

13. Safety Features

This furnace is protected with electrical safety features to trip the supply on continuous overload or short circuit.

The thermal heating is protected by an independent over-temp cut-out to trip the supply.

For personal safety, we strongly recommend the use of protective clothing including face masks or goggles. In addition, thermal gloves and / or thermal insulated tongs used when inserting or removing hot objects from the furnace.

It is recommended to have a local heat resistant surface or brackets / holders to receive hot objects / probes removed from the furnace.

14.Automatic Calibration and Furnace Control

Refer to Appendix 7 furnace automatic calibration system diagram.

This furnace can be used with the TTI7 PRT / TC multichannel digital thermometer or DVM's / Scanner systems, in order to automatically ramp the furnace to several pre-set control temperatures . When stability is reached and monitored by the reference probe and software at each set point (set in the PC software) the TTI7 / scanner will scan and record the reference and unknown probes . The data at each temperature with probe serial number and customer reference is stored in a data file . A TTI7 RW automatic report writer used in conjunction with the TTI7 E calibration software can calculate and print out a complete calibration report. Alternatively the TTI7 E data files can be downloaded to other information and report writing systems.

Refer to TTI7 E software manual and the CP10 Calibration Procedures manual Section 2 for further details and instructions.

This provides fully automatic calibration at a pre-set number of temperature points, with the system unattended

970 TYPE 3-ZONE HORIZONTAL THERMOCOUPLE CALIBRATION FURNACE WITH METAL EQUILISATION BLOCK FOR OPERATION TO 1200 Deg.C.

Control principle of 3 Zone furnace

(Illustrates automatic Master - Slave end zone operating principle)

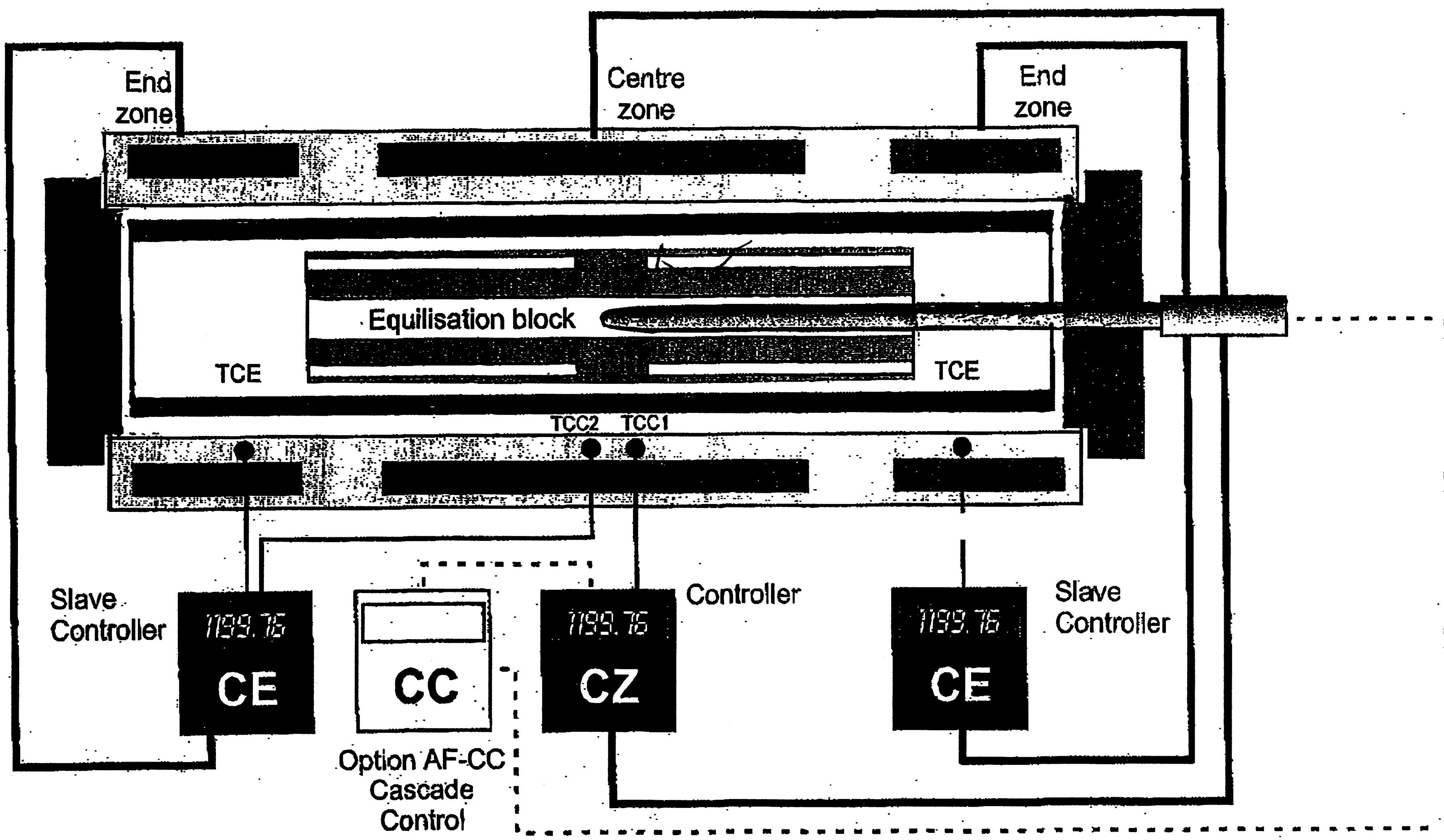

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DIAGRAM 7.

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Appendix 3

970-2 CALIBRATION TUBE FURNACE
Type EB3 – 970-2 Metal equalizing block drilling & probe sizes, end A

INCONNEL EQUALISING BLOCK DRILLING & PROBE SIZES

END 'A'

Block size 9.4 ins. Long x 2.88 ins. Diameter.

HOLE DRILLING
6 x A / B counterbored.
A=6.3 mm.(0.248 ins.) 4.625 in. deep.
B=10 mm.(0.394 ins.) 1.375 in. deep.

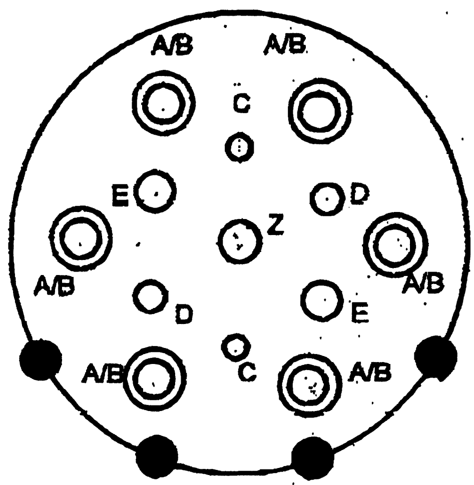
2 x C 4 mm. (0.157 ins.) x 3.25 in. deep.

2 x D 6.5 mm (0.256 ins.) x 3.25 in. deep

2 x E 6.8 mm (0.268 ins.) x 4.625 in.deep

1 x Z 7 mm (0.276 ins.) drilled through end to end of block

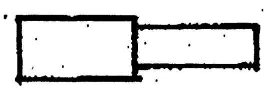
HOLE CENTRES
6 x A / B on 2 ins. P.C.D.
2 x C, D, E, on 1.25 in. P.C.D.

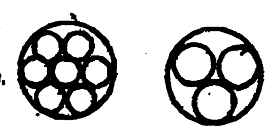


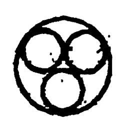
4 x ceramic spacers

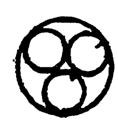
HOLES AND PROBE SIZES

Hole Ref.	Hole Dia.	Hole Qty.	Probe capacity and sizes.
A / B	6.3/10	6	6 off stepped : 0.238 in.dia.for 3 in. then 0.378 in.
C	4 mm	2	2 x 6 off 0.04 in.dia.(0.05 in.with tol.) in each hole Assembled with dummy centre rod. OR 2 x 3 off 0.083 in.dia.(0.073 in. with tol.) each hole. OR 2 off 0.14 in. dia. Max.
D	5.5mm	2	2 x 3 off 0.09 in.dia (0.10 in. with tol.) in each hole. OR 2 off 0.20 in. dia. Max.
E	6.8mm	2	2 x 3 off 0.114ins. dia. (0.124in. with tol.) in each hole. OR 2 off 0.25 ins. Dia. (0.26 in. with tol.) in each hole.









NORTH AMERICA **Appendix** 4

970-2 CALIBRATION TUBE FURNACE
Type EB3 – 970-2 Metal equalizing block drilling & probe sizes, end B

INCONNEL EQUALIZING BLOCK DRILLING & PROBE SIZES

END "B"

Block size 9.4 ins.long x 2.88 ins. Diameter

HOLE DRILLING

8 x E 6.8 mm. (0.268 ins.) x 4.625in. deep

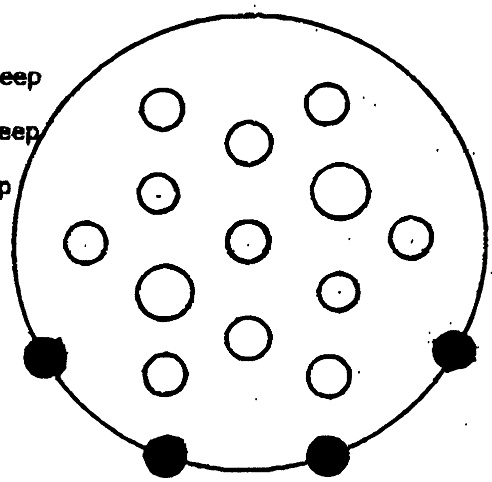
2 x F 7.0 mm. (0.276 ins.) x 4.625in. deep

2 x G 9mm.(0.354ins.) x 3.75 ins. Deep

1 x Z 7mm.(0.276 in.) drilled through end to end of block.

HOLE CENTRES

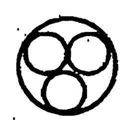
6 x E on 2 in. P.C.D.
2 x E, F, G on 1.25 in. P.C.D.

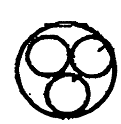


4 x ceramic spacers

HOLE AND PROBE SIZES

Hole Ref.	Hole Dia.	Hole Qty.	Probe capacity and sizes.
E	6.8mm	8	2 x 3 off 0.114 ins. Dia. (0.124in. with tol.) in each hole. OR 8 off 0.25 ins. Dia. (0.26in. with tol.)
F	7.0mm	2	2 x 3off 0.125 in. dia. (0.135 in. with tol.) in each hole. OR 2 off 0.246 ins. Dia. (0.256 ins. with tol.)
G	9.0mm	2	2 off 0.34 ins. dia. Max. (insertion depth 3.5 ins.)





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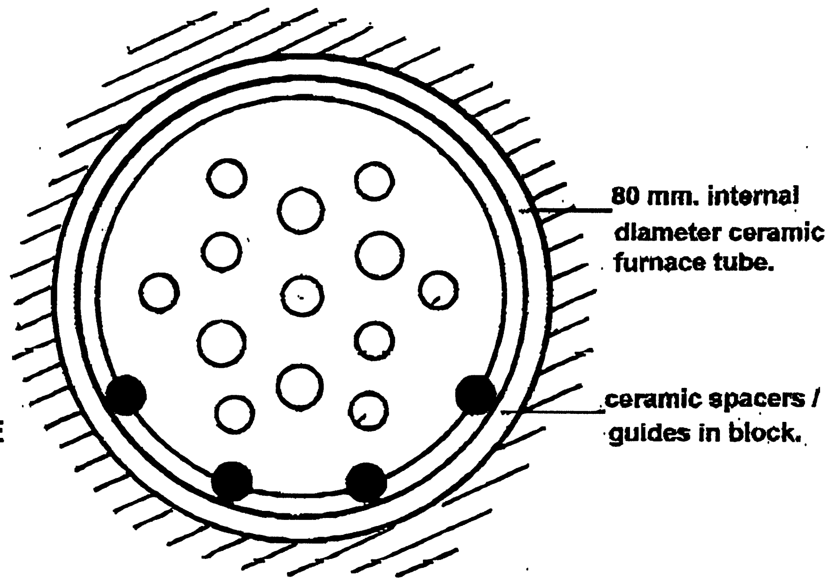
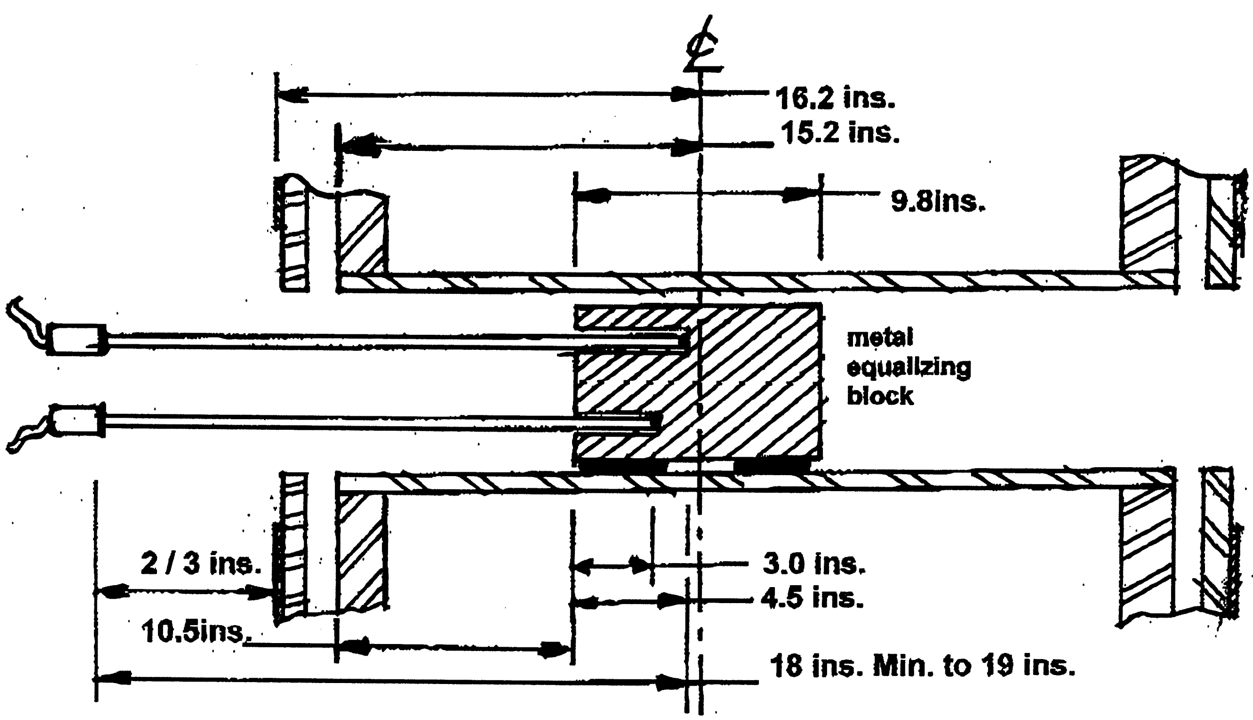
Appendix 5

970-2 CALIBRATION TUBE FURNACE
Equalizing Block furnace assembly
& Standard Probe mounting depths

EQUALIZING BLOCK LOCATION IN MODEL 970-2 CALIBRATION FURNACE





INSERTION DEPTH & EQUALIZING BLOCK POSITION -- "STANDARD" PROBES

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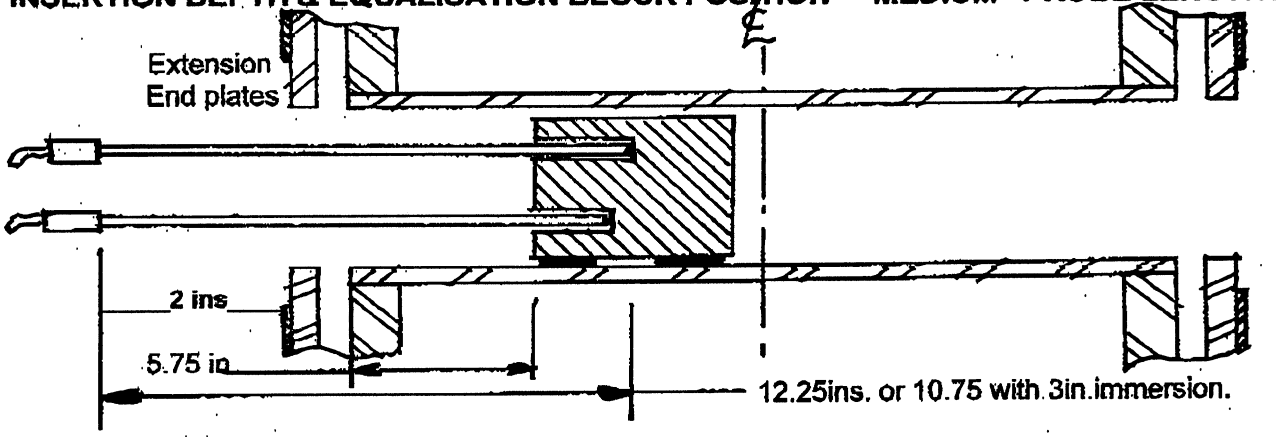
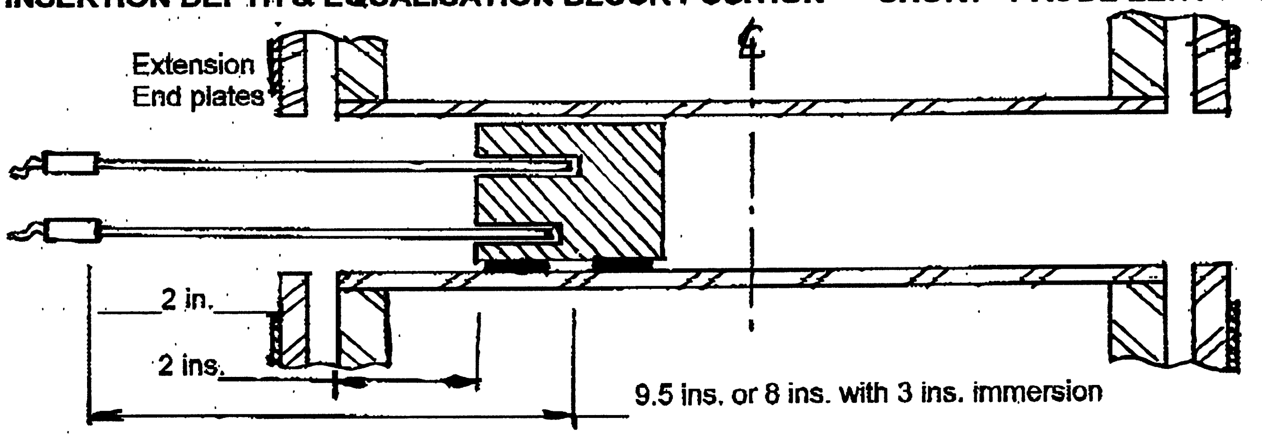
Appendix 6

970-2 CALIBRATION TUBE FURNACE
Probe Mounting depth arrangement
(Medium, Short, Extra short probes)

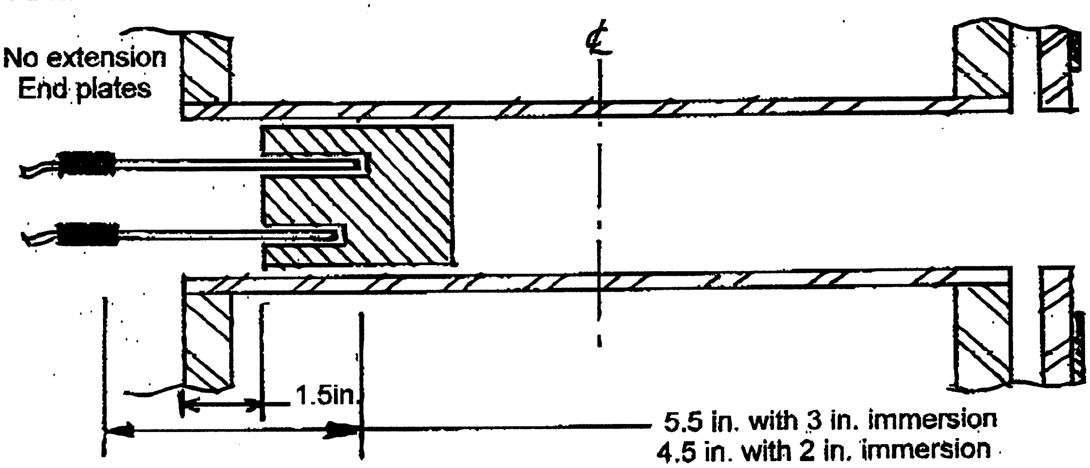
INSERTION DEPTH & EQUALISATION BLOCK POSITION - "MEDIUM" PROBE LENGTHS



INSERTION DEPTH & EQUALISATION BLOCK POSITION – "SHORT" PROBE LENGTHS



INSERTION DEPTH & EQUALISATION BLOCK POSITION – "EXTRA SHORT" PROBES



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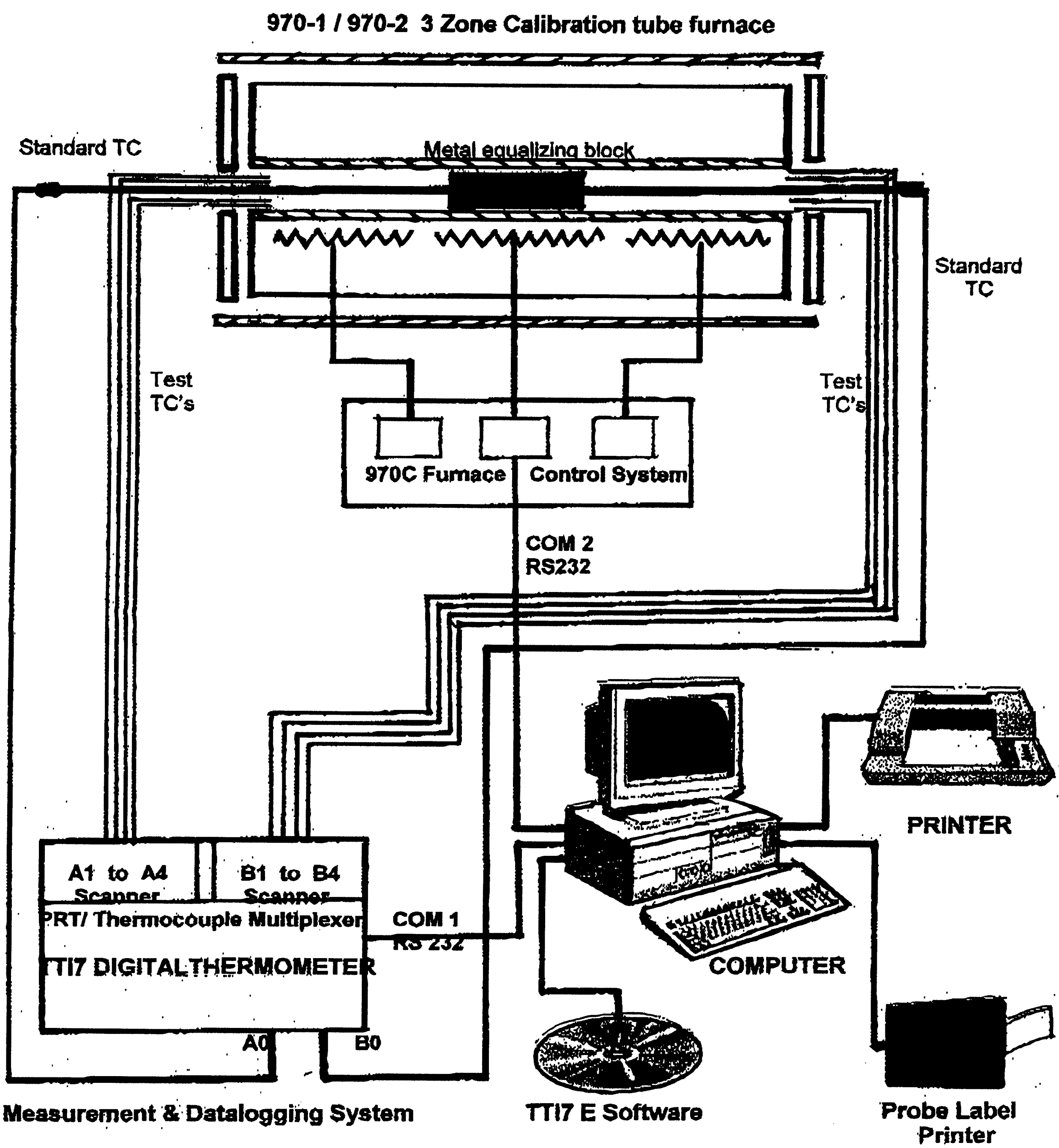
THERMOCOUPLE CALIBRATION SYSTEM
970 3 Zone tube furnace & TTI Digital Thermometer with Automatic PC Control



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THERMOMETRY UNCERTAINTIES
Report TU 2
Immersion Depth Errors

INTRODUCTION

It is a fundamental rule of temperature measurement that the temperature a thermometer measures is its own temperature. This argues that a thermometer, to measure the temperature of some site, must be immersed in the site sufficiently so that the sensor has reached the site temperature. The purpose of this article is to develop some simple and practicable rules to help in the consideration of immersion depths.

REVIEWING EXISTING LITERATURE

One text to consult for guidance is a book called Supplementary Information to the International Temperature Scale of 1990[1].

Section 3.2.4 says:

A thermometer is sufficiently immersed when there is no change in indicated temperature with additional immersion in a constant temperature environment...

The immersion required to exploit the full accuracy of the thermometer is highly dependent both on the temperature being measured and the thermometer design. The latter should, of course, facilitate radial and inhibit longitudinal thermal radiation...

...Although at temperatures above room temperature the required immersion depth initially increases with temperature, a maximum is reached in the region of 400° to 500°C, after which the rapidly- rising radial heat transfer by radiation causes it to fall slightly; this is on the assumption of the presence of adequate longitudinal radiation baffles and the inhibition of radiation piping.

Additional guidance may be found in the excellent book Traceable Temperatures [2]. (Figs. 1, 1.1 and 1.2 in this article are taken, with acknowledgment, from this volume). The text deals with immersion depths in a very practical way, and the authors are brave enough to put numbers to their descriptions.

They say about immersion depths:

"The general problem occurs because there is a continuous flow of heat along the stem of a thermometer between the medium of interest and the outside world. Since heat can flow only where there is a temperature difference, the flow of heat is evidence that the tip of the thermometer is at a slightly different temperature than that of the medium of interest."

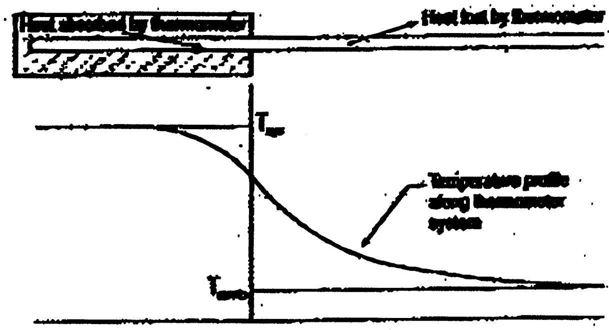

FIG. 1: The flow of heat down the stem of a thermometer causes the thermometer to indicate temperatures lower than the medium of interest.

This is shown graphically in Fig. 1. The flow of heat down the stem of a thermometer causes the thermometer to indicate a temperature slightly lower than that of the medium. A simple model of this effect relates the error in the thermometer indication to the length of immersion by:

$$\Delta T_m = (T_{amb} - T_{sys})\, k \exp(-L/D_{eff})$$

where T_{sys} and T_{amb} are the system and ambient temperatures respectively, L is the length of the thermometer immersed, D_{eff} is the effective diameter of the thermometer and k is a constant approximately equal to but less than 1. This equation, which is plotted in Fig. 1.1 for k=1, is very useful for determining the minimum immersion that will assure that the error due to stem conduction is acceptable.

THERMOMETRY UNCERTAINTIES
Report TU 2
Immersion Depth Errors

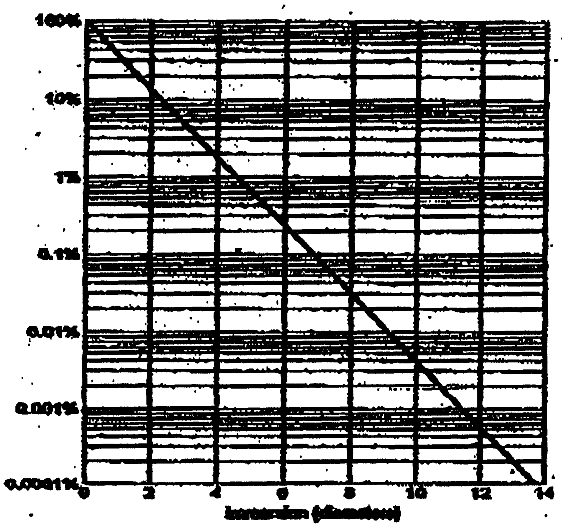

Fig. 1.1: The relative temperature error $[\Delta T_m/(T_{sys}-T_{amb})]$ plotted against thermometer immersion depth in diameters. This graph is appropriate to sensors in stirred liquid baths.

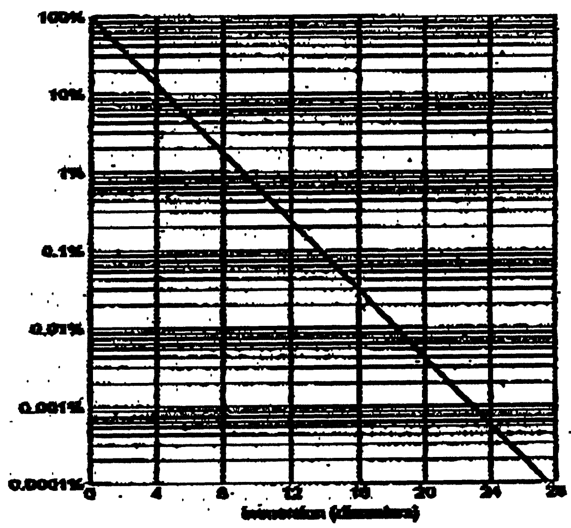

Fig 1.2: The relative temperature error $[\Delta T_m/(T_{sys}-T_{amb})]$ plotted against thermometer immersion depth in diameters. This graph is appropriate for sensors where $D_{w}/D = 2$, such as in a dry block calibrator.

From Fig. 1.1, we can deduce three useful rules of

(1) For "industrial;" thermometers an immersion of 5 diameters should be suitable for 1% accuracy.

(2) For good laboratory thermometry, we can recommend 10 diameters of immersion for 0.01% accuracy.

(3) For best laboratory practice we can recommend 15 diameters of immersion for 0.0001% accuracy.

These immersions may be suitable for a thermocouple junction or a tiny thermistor. For a probe containing a PT-100 sensor, the length of the actual sensitive element should be added to the immersion depth, since none of the sensing element length should be within the stem conduction gradient.

We now have a formula and a graphical representation that will provide good results in a "well-stirred" oil bath. The Supplementary Information [1] reference suggests a temperature dependence that we have not taken into account in this expression. However if we calculate the immersion depth required for the accuracy we seek a temperature of 500°C, we should have covered the ground.

Having identified three immersion depths for (1) industrial, (2) laboratory and (3) best practice, we can now deal with each of these in more detail.

INDUSTRIAL THERMOMETRY

Typical and similar examples of an industrial application might be a thermocouple in a thermowell or in a dry block calibrator.

A thermowell is intended either to protect the thermometer from the process environment, or to seal off the environment so that the thermometer may be removed without loss of process medium. The well may be screwed, bolted, welded, etc, into the process vessel. Commonly it may have length to diameter ratio of 1 to 5 or more (e.g. 1 inch diameter by 5 inch length). In considering immersion depth it is necessary to think about the outside diameter of the "installation"; that is of the well, rather than the diameter of the probe within the well.

Another example is the dry-block calibrator. These small furnaces usually comprise a cylindrical metal insert, provided with holes for insertion of thermometers under test, the insert surrounded by

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THERMOMETRY UNCERTAINTIES
Report TU 2
Immersion Depth Errors

Again, one must think about the diameter of the insert, not of the thermometers. A usual diameter for such an insert is 50mm; if you are lucky or provident, your insert may be 250mm long; a 1 to 5 ratio. Typically the temperature at the bottom of the insert is controlled to about 1%, and while the radial distribution of heat is reasonably uniform the axial gradient may be less well controlled. And no matter what your thermometer diameter, the immersion errors will normally be dominated by the poor immersion characteristics of the insert.

These errors can be largely overcome if:

(a) you do not rely upon whatever temperature is indicated by the heater controller, but instead provide an independent reference thermometer, placed in the insert at the same axial location as the thermometer under test.

(b) the reference thermometer is as like as possible in its construction and thermodynamic characteristics as the thermometer under test.

Indeed, such an arrangement of reference thermometer and thermometer under test is implicit in ISO 9000 requirements.

Sensors in thermowells or dry block calibrators will not absorb or lose heat in the same way as sensors in stirred liquid baths, and Nicholas' and White's figure does not directly apply. That is because the figure assumes that:

$$D_{eff}/D_{sensor} \approx 1 \qquad \text{Eq.2}$$

as it is for stirred baths. However in situations that involve an air gap, such as the thermowell or block bath,

$$D_{eff}/D_{sensor} > 1 \qquad \text{Eq.3}$$

Let me therefore provide a second example where we wish to calibrate a 6mm diameter thermocouple at 500°C above ambient in a metal block bath, to an accuracy of 0.5°C:

$$[\Delta T_m/(T_{bath}-T_{amb})] = 0.5/500 \approx 0.1\% \qquad \text{Eq.4}$$

Then, referring to Fig. 1.1, I find that for $D_{eff} = D = 1$ the minimum immersion is 7 diameters or 42mm. However if $D_{eff} = 2D$, the required immersion would increase to 84mm. For industrial platinum thermometers we must add about 40mm to account for the sensor length, requiring then immersion of 120mm. In addition, we will look for greater accuracy with platinum sensors than with thermocouples (say 0.05°C) calling for an additional 25mm, making for a total immersion of 145mm.

Nicholas and White do not provide figures of D_{eff}/D for metal block calibrators or for the thermowell situation. Fortunately at Northern Temperature Primary Laboratory, we have fully evaluated many metal block baths of our own design and production, at many temperatures, over a number of years.

Using the accuracy figure of 0.5°C as a criterion, I find, as a generality and almost irrespective of the temperature (testing at 250°, 450° and 650°C) that 80mm immersion is required for a 6mm type N thermocouple placed in a 6.5mm hole in the metal insert block for the stem conduction/vertical thermal profile of the insert to be less than 0.5°C. This confirms my employment of $D_{eff}/D = 2$.

<u>**GOOD LABORATORY PRACTICE**</u>

For laboratory thermometers less uncertainty is required. As a practical example, we might determine the minimum immersion depth for a 4mm diameter thermometer with the sensitive element occupying the last 40mm of the sheath. We will set a criterion for immersion error of less than 0.01°C at temperatures up to 100°C:

$$[\Delta T_m/(T_{bath}-T_{amb})] = 0.01/(100-20) \approx 0.01\% \qquad \text{Eq.5}$$

Referring to Fig. 1.1, we find that the minimum immersion of a little more than 9 diameters. To be conservative, we will immerse the thermometer to 10 diameters beyond the detector element; i.e., 80mm total immersion. While 5 diameters minimum is a useful rule of thumb for industrial usage (≈±1%), 10 diameters (≈±0.01%) may be the choice for more accurate thermometry.

<u>**BEST LABORATORY PRACTICE**</u>

Best laboratory practice (e.g., for the most exacting measurements, such as Standard Platinum Resistance Thermometers (SPRTs) in fixed point cells present us with a puzzle: The immersion of the thermometer below the surface of the metal ingot of a fixed point cell is typically 160mm to 200m, and the SPRT may require 300mm of immersion. How can it be, then, that the most exacting measurements are made with such blatantly insufficient immersion.

The answer is that the temperature above the fixed point cell, and for a further height of 200mm, is typically within 0.5°C of the cell itself, and is further conditioned with insulation against convection and conduction and with radiation baffling, that reduces the temperature gradient and consequently the immersion depth required.

For example, consider a zinc cell that allows 200mm of immersion below the surface of the ingot of zinc, and that has a liquid-solid equilibrium temperature (the temperature at which the measurement is to be made) of 419°C.

If ΔT_m is to be 0.0001°C, it would appear that we need an immersion depth of 32 diameters plus the length of the sensitive element, reading from Fig. 1.2, since the thermometer is in an air gap:

$$[\Delta T_m/(T_{sys}-T_{amb})]=[0.0001/400] \approx 0.00002\% \quad \text{Eq.6}$$

But consider that for a height of 200mm the temperature gradient along the thermometer stem is only 0.5°C. The measurement then becomes 0.0001/0.5 = 0.0002, or only 15 diameters plus the length of the sensitive element. For an 8mm diameter SPRT, 128mm of immersion depth has been saved ! This means that 130mm less immersion in the cell itself is required; only 170mm is required.

The above example suggests ways in which, under some circumstances, immersion errors may be further controlled. Assume that a thermometer is inserted into a metal insert that in turn is inserted into a metal block furnace, and that the insert is shorter than the length of the throat above the furnace. Perhaps a heat-insulating cover is provided over this air space to reduce heat loss by convection. Then the thermometer stem heat loss is reduced by the temperature of the confined air space, which is certainly higher than ambient. The reduction of required immersion for a thermometer in a thermowell may be similarly regarded.

We can use this knowledge to improve the performance of items such as the metal inserts mentioned in the Industrial Thermometry section of this article. If the insert (like the fixed point cell, in the example just given) is beneath the top of the heated throat of the dry block calibrator, a thermometer placed in it is not subject to the same stem conduction effects of a thermometer that exits directly into ambient temperature. Sensors placed in such an insert are subject to stem conduction errors only after they exit the calibration system.

Thus a good compromise is reached, whose mathematical model is beyond the scope of this article; but the standard immersion test of withdrawing the sensor 1 or 2 diameters will amply demonstrate the improved performance.

The above review indicated the ways of predicting the immersion depth required for various temperature sensors in various configurations and applications. The practical illustrations should enable the reader to better design and industrial installation of select calibration equipment. However a word of caution: the above is a guide only. There are always exceptions, so follow Nicholas and White's advice:

"In all cases where immersion errors are suspected it is a simple matter to vary the immersion depth by one or two diameters to see if the reading changes. As a crude approximation, about 60% of the total error is eliminated each time the immersion is increased by one effective diameter".

REFERENCES

[1] Supplementary Information for the International Temperature Scale of 1990, Bureau International des Poids et Mesures, Sévres, France (1990)

[2] J.V.Nicholas, D.R.White, Traceable Temperatures, John Wiley and Sons (1994)