TRUE SURFACE TEMPERATURE MEASUREMENT SYSTEM MODEL 944

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CONTENTS

EMC INFORMATION

This product meets the requirements of the European Directive on Electromagnetic Compatibility (EMC) 89/336/EEC as amended by EC Directive 92/31/EEC.

The product meets the susceptibility requirements of EN 50082-1, criterion B.

ELECTRICAL SAFETY

This equipment must be correctly earthed.

This equipment is a Class 1 Appliance. A protective earth is used to ensure the conductive parts cannot become live in the event of a failure of the insulation.

The protective conductor of the flexible mains cable which is coloured green/yellow MUST be connected to a suitable earth.

The Blue conductor should be connected to Neutral and the Brown conductor to Live (Line).

Warning: Internal mains voltage hazard. Do not remove the panels.

There are no user serviceable parts inside. Contact your nearest Isotech agent for repair.

Voltage transients on the supply must not exceed 2.5kV.

HEALTH AND SAFETY INSTRUCTIONS

1. Read all of this handbook before use.

2. Wear appropriate protective clothing.

3. Operators of this equipment should be adequately trained in the handling of hot and cold items and liquids.

4. Do not use the apparatus for jobs other than those for which it was designed, ie. the calibration of thermometers.

5. Do not handle the apparatus when it is hot (or cold), unless wearing the appropriate protective clothing and having the necessary training.

6. Do not drill, modify or otherwise change the shape of the apparatus.

7. Do not dismantle the apparatus without disconnecting it from the supply and leaving time for it to reach ambient temperature.

8. Do not use the apparatus outside its recommended temperature range.

9. If cased, do not return the apparatus to its carrying case until the unit has cooled.

10. There are no user serviceable parts inside. Contact your nearest Isotech agent for repair.

11. Ensure materials, especially flammable materials are kept away from hot parts of the apparatus, to prevent fire risk.

12. Ensure adequate ventilation when using oils at high temperatures.

13. Each apparatus is protected by an over temperature circuit. Please consult handbook for details.

Product covered by this document are described in our manual attached.

GUARANTEE

This instrument has been manufactured to exacting standards and is guaranteed for twelve months against electrical break-down or mechanical failure caused through defective material or workmanship. Failure caused by misuse is not covered. In the event of failure covered by this guarantee, the instrument must be returned, carriage paid, to the supplier for examination, and will be replaced or repaired at our option.

FRAGILE CERAMIC AND/OR GLASS PARTS ARE NOT COVERED BY THIS GUARANTEE

INTERFERENCE WITH, OR FAILURE PROPERLY TO MAINTAIN, THIS INSTRUMENT MAY INVALIDATE THIS GUARANTEE

RECOMMENDATION

The life of your **ISOTECH** Instrument will be prolonged if regular maintenance and cleaning to remove general dust and debris is carried out.

Serial No:..

Date:..

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The Company is always willing to give technical advice and assistance where appropriate. Equally, because of the programme of continual development and improvement, we reserve the right to amend or alter characteristics and design without prior notice. This publication is for information only.

<u>SAFETY PRECAUTIONS</u>

1. Please read this manual before operating the instrument.

2. All warnings, notes, etc. within this manual must be observed.

3. The TTI 4 system is maintenance free. Servicing should be carried out by qualified personnel only.

4. Disconnect power before servicing or removing parts.

5. When using the TTI 4 any operating conditions that cause damage to objects or danger to human beings must be avoided.

6. The measuring results of the TTI 4 system not only depend on the correct functioning of the instrument itself but also depend on various other conditions, such as the calibration of the surface sensor.

Therefore, the results must be verified by an expert before further steps based on those results are taken.

7.The compensated surface sensor is often and by its nature **<u>HOT</u>**. Appropriate precautions must be observed when handling the sensor.

INTRODUCTION

Surface temperature measurement with contact thermometers has always been a problem because of the heat flux from the surface being measured affects the surface temperature, and the temperature as indicated by the measuring sensor.

The following article describes the problems and the principle of operation of the Isotech True Temperature Indicator 4.

TRUE SURFACE TEMPERATURE MEASUREMENT

Summary:

The mechanism of surface temperature sources of error are described. These all have to do with conduction of heat away from the surface being measured. By thermally compensating for these conduction mechanisms a new and novel device is described that will measure true surface temperature. This device, already in production and use has reduced errors by up to **95%**.

Introduction:

As soon as a measuring device is attached to a surface heat flows from the hot to the cold surface.

This for a hot surface means that the surface is cooled locally, and that the measuring device is heated. The rate at which heat is transferred depends on the thermal contact between surface and measuring device. Often silicone grease or other conducting material is introduced, to help conduction. The smoothness of the surface also affects the heat flow.

What would be ideal is a surface sensor that generated an equal and opposite heat flux reflected back into the surface.

This would eliminate all the errors associated with surface temperature measurement.

Causes of measurement errors:

There are three main problem areas in determining the surface temperature of a solid which is in equilibrium with the surrounding atmosphere, which we shall call the first, second and third partial error.

The first partial error results from the loading effect on the object being measured by bringing a cold measuring probe into contact with it. The heat flow from the surface of the object in contact with the probe increases from its equilibrium value as flux is drawn up the probe. The result is a disturbance of the temperature field and a drop in surface temperature at that point. This error is particularly severe with non-metallic objects where the low thermal conductivity of the object results in large temperature field disturbances.

The non-ideal contact conditions between the probe and the object surface result in a thermal resistance at the interface between the two. The intense heat flux up the probe has to pass through this resistance, and a temperature drop is experienced, resulting in the second partial error.

The third partial error is caused by the temperature drop with distance from the surface of the object being measured to the sensitive point of the probe which is responsible for the thermometer readings. Due to the physical construction of the probes, this distance, /, is non-zero. Figure 1 shows the effects of these three partial errors on the reading of the contact thermometer.

These three errors can be represented by the following equations [1]:

1.
$$\epsilon_1 = -\frac{R_T}{\lambda_b} (F_m) . q_d$$

2.
$$\epsilon_2 = -W_c . \varphi_T$$

3.
$$\epsilon_3 = -\frac{1}{\lambda_T} . q_T$$

where: q_d = nett heat flux density up probe

q_T = total heat flux density up probe

φ_T = total heat flux up probe

R_T = radius of the probe

λ_b and λ_T = thermal conductivity of the object probe respectively

W_c = contact resistance

and F_m = constant

From these equations it can be seen that all three errors are proportional to either the heat flux or the heat flux density that flows up the measuring probe due to the temperature gradient between object and probe. If this heat flux can be reduced, then it follows that the errors of measurement will also be reduced.

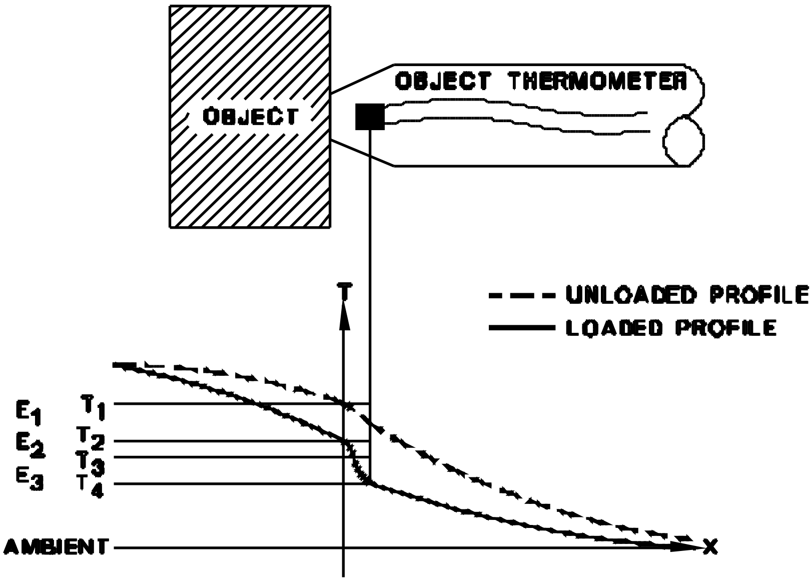
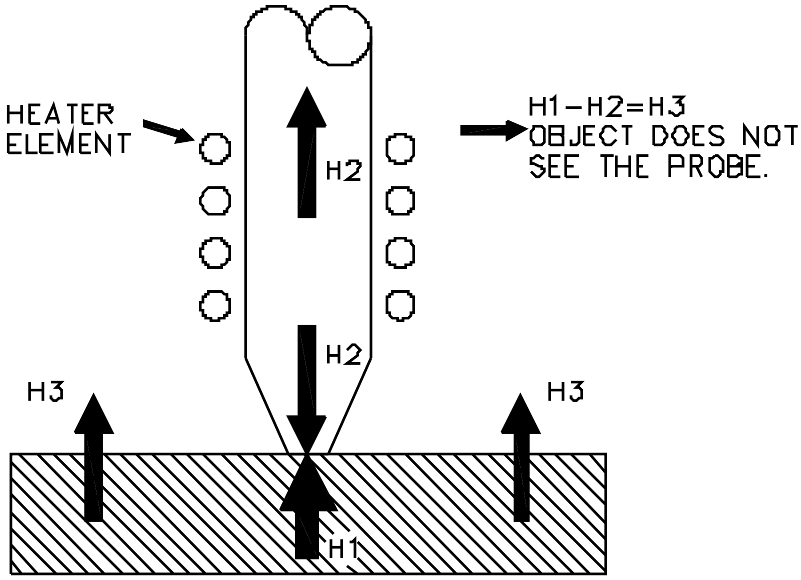


Figure 1 - Temperature Profile through Object and Measurement Probe.

A THERMALLY COMPENSATED PROBE

The intense heat flux that flows up the probe when brought into contact with the object being measured is as a result of the large temperature difference between the hot object and the cold probe. If this temperature gradient can be reduced the heat flux, and hence the three partial

errors,
will be reduced.



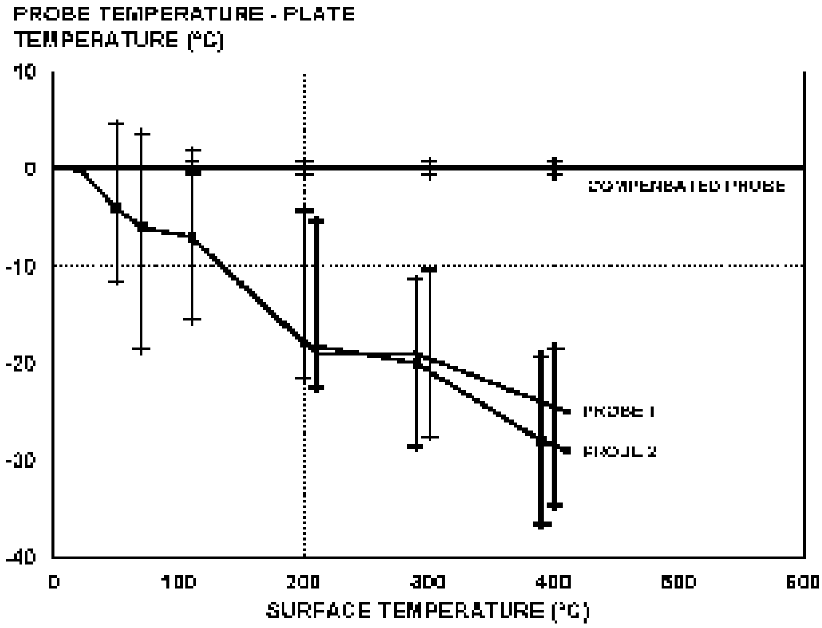
A schematic of a thermally compensated probe is shown in figure 2. A heaterelement is wound around the probe near the sensing tip, and is used to raise

Figure 2. Schematic of a thermally compensated probe.

the temperature of the probe to the same as that of the object being measured. When the probe is brought into contact with the object, the temperature field at the object surface is no longer disturbed, as the difference between the heat flux drawn up by the probe, H1, and the heat supplied by the probe, H2, is equal to the equilibrium heat flux, H3, that would flow into the atmosphere if the probe were not present.

Results of a thermally compensated probe and two standard probes is shown in figure 3. The reduction in heat flux up the probe resulted in a vast reduction in the measurement errors. Furthermore, the temperature field of the object was not disturbed, and thus a measure of the true, unloaded surface temperature could be made.

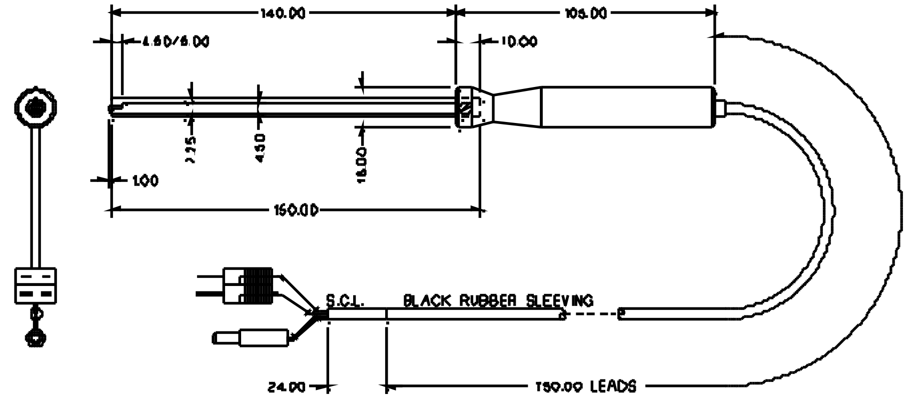
Figure 3:



The Practical Realization

To be useful, the practical realization of the concepts described above needs to be of similar dimensions to a standard surface temperature measuring probe.

A diagram of the device is shown below:



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Also now commercially available is a control and temperature indicator package.

Conclusion

The troublesome problem associated with surface temperature measurement have been defined and analysed. A practical solution has been proposed which removes up to 95% of the errors associated with surface temperature measurement.

A practical embodiment of the device is now commercially available.

N.B. This Author wishes to acknowledge the contribution to this article of B.D. Foulis of N.M.L. from whom much of the material is derived.

TTI 4 SYSTEM

Description:

Comprises a temperature compensated surface probe and an indicator/controller.

The probe is fragile by its nature and must be handled with care.

Generally no oil or grease is necessary between probe and surface. Introducing any compound will affect the results and may prevent proper operation of the probe (see Tutorial).

There are 3 connections between the probe and the controller/indicator.

Two type N thermocouple plugs and one heater plug. Connect all three into the rear panel of the controller/indicator.

Connect the controller/indicator to the mains and switch on.

The controller is a temperature deferential device and its purpose is to heat the compensated probe to the same temperature as the surface being measured. The units displayed are somewhat arbitrary and the controller is trying to achieve 0.0 for ideal compensation.

The indicator indicates the temperature of the probe. It is a type N thermocouple and will be accurate within either the normal type N thermocouple uncertainties or as quoted on the calibration report, if one has been ordered.

See figures 4 & 5.

Figure 4 - Front View

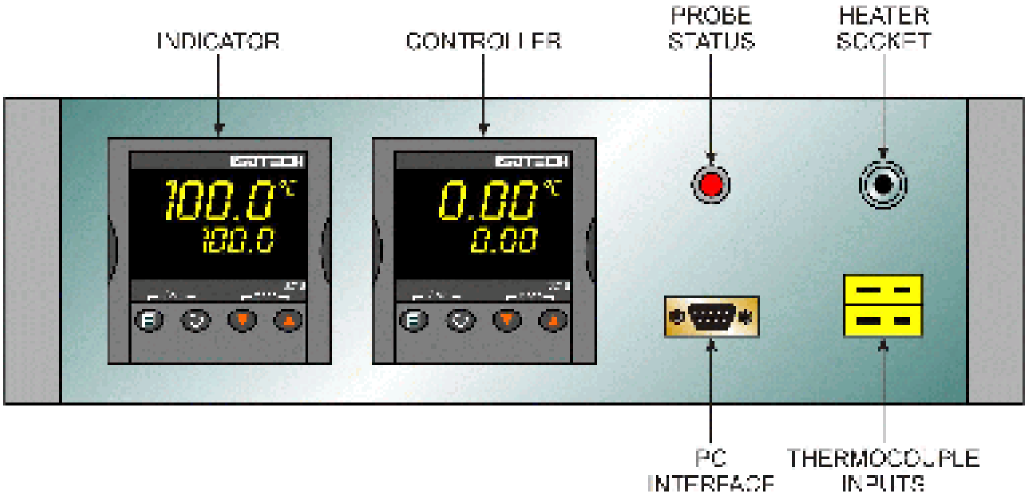
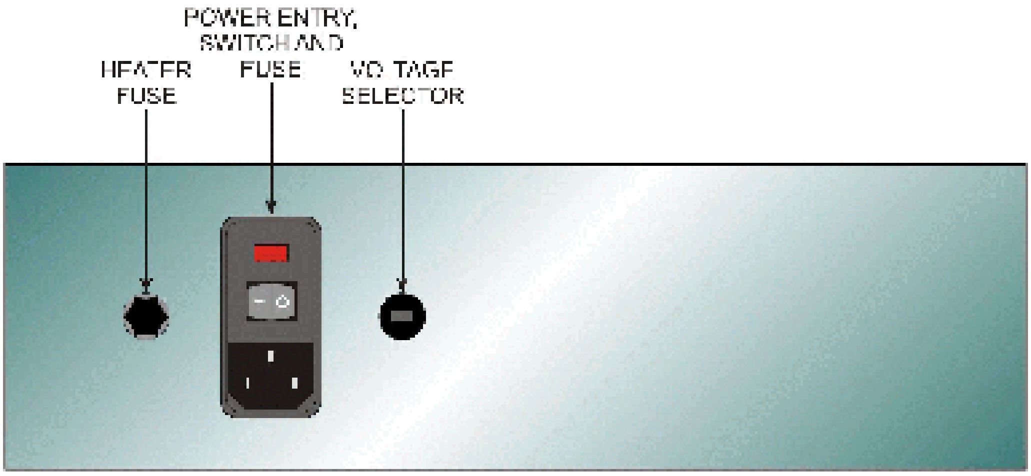


Figure 5 - Rear View



OPERATION

Operation is very simple. In an ambient with no air movement, place the probe at right angles onto the surface to be measured.

The probe MUST be positioned on the surface before powering up the TTI 4.

In general DO NOT use conducting liquids (see Tutorial) on the surface. For best results using a TTI 4 and surface probe measurement system the surface should be clean and smooth.

The outer sheath of the probe has a small clear area near the tip, this is to allow the user to position the tip flat against the surface to give maximum contact.

At all times during use the probes measuring junction should be flat against the surface to be measured. This can be achieved using very slight pressure, however the weight of the probe is ideal to provide sufficient contact for it to work correctly. Variable pressure will as with hand held measurements cause the compensation and hence the reading to vary, so arrange for the support to be a clamp rather than holding the probe by hand.

The TTI 4 can now be powered up.

Next wait until the probe temperature has stabilised and the controller is reading approximately 0. The reading will then be the true temperature of the surface.

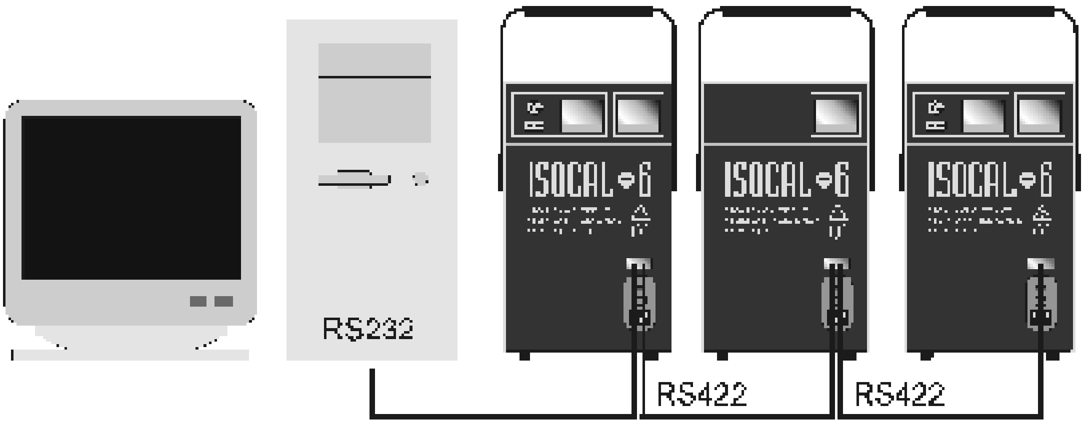
As an experiment remove the heater plug from the rear of the controller/indicator and see the error when the probe is not compensated.

If the reading is unstable then using the 'auto tune' at 'set point' may improve this - see controller instructions. However, this is not advised if the instrument has been calibrated.

Using the PC Interface

The TTI 4 includes an RS422 PC interface and a special converter cable that allows use with the a standard RS232 port. When using the unit with an RS232 port it is essential that this converter cable is used. Replacement cables are available from Isotech, part number ISO-232-432. A further lead is available as an option, Part Number ISO-422-422 lead which permits up to 5 instruments to be daisy chained together.

The benefit of this approach is that a number of calibration baths may be connected together in a "daisy chain" configuration - and then linked to a single RS232, see diagram.



Note: The RS 422 standard specifies a maximum lead length of 1200M (4000ft). A true RS422 port will be required to realise such lead lengths. The Isotech conversion leads are suitable for maximum combined lead lengths of 10M that is adequate for most applications.

Connections

For RS232 use simply connect the Isotech cable, a 9 to 25 pin converter is included to suit PCs with a 25 pin serial converter.

RS422 Connections

Pin	Connection
4	Tx+ A
5	Tx- B
8	Rx+ A
9	Rx- B
1	Common

Using the Interface

The models are supplied with Cal NotePad as standard. This easy to use package is compatible with MS Windows 9x. A handbook for Cal NotePad can be found on the first installation disk in

Adobe PDF format. If required a free Adobe PDF reader can be downloaded from, www.adobe.com.

CAL NOTEPAD

Cal Notepad can be used to log and display values from the equipment and an optional temperature indicator.

Minimum System Requirements

CNP requires Windows 95 / 98, a minimum of 5Mb of free hard drive space and free serial ports for the instruments to be connected.

Development

CNP was developed by Isothermal Technology using LabVIEW from National Instruments.

License

Use of the Cal NotePad software program "CNP" is as granted in this license agreement. In using the CNP
software the user "licensee" is agreeing to the terms of the license. You must read and understand the terms of this license before using CNP.
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4, It is the responsibility of the user to ensure the validity of all stored results and printed certificates. Isothermal Technology Ltd accept no responsibility for any errors caused by inappropriate use, incorrect set up or any other cause; including defects in the software.
5, Limited Warranty. Isothermal Technology warrants that CNP will perform substantially as described in this manual for a period of 90 days from receipt. Any distribution media will under normal used be guaranteed for a period of 90 days.

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CNP is not designed for situations where the results can threaten or cause injury to humans.

Installing Cal NotePad

1. Insert CNP DISK 1 into the disk drive
2. Click on the START button on the task bar, select RUN, type A:\SETUP (Where A: is your drive letter) then click OK
3. Follow the prompts which will install the application and necessary LabVIEW run time support files.
4 Should you ever need to uninstall the software then use the Add/Remove Programs option from the Control Panel.

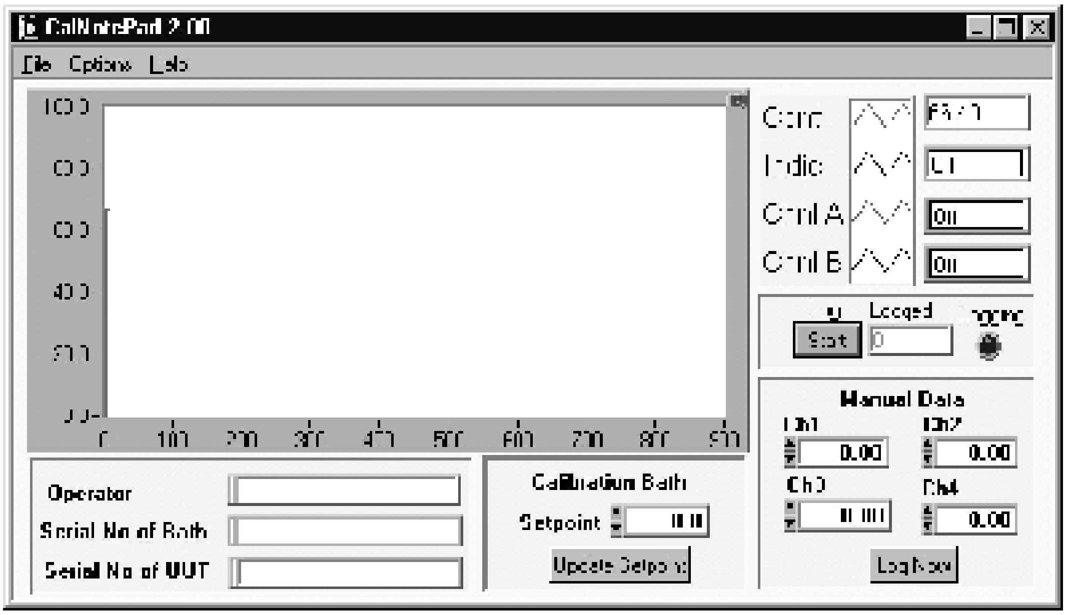
Starting Cal NotePad

From a Standard Installation:

Click the START button

Highlight PROGRAMS

Select Isotech - Select Cal pad



Protocol

The instruments use Modbus (3216 controller)

If required, e.g. for writing custom software the technical details are available from our website at, www.isotech.co.uk/refer.html

TUTORIAL

Calibrating Contact Surface Temperature Sensors using the Isotech Small Hotplate Model 983 (50°C to 350°C) and the calibrated Surface Probe System Model 944 (30°C to 350°C).

INTRODUCTION

Surface temperature measurement has always been a problem.

Perhaps the problem is best expressed by Nichols & White in their book `Traceable Temperatures' ISBN 0471938033. They say:

A surface, because it is the interface between 2 systems, does not have a temperature as such. A user who wants to know a `surface temperature' should define his measurement problem more exactly - see Appendix 1 for the full text.

One major problem with all contact surface measurements, except the compensated probe of the Model 944 (TTI 4), is that the act of making the measurement significantly affects the temperature of the surface being measured, due to the heat flow from the surface to the probe.

Ideally all contact thermometers should be the compensated probe type where no heat flows between surface and probe. Currently these are the only surface measurement probes, which because their thermal compensation enables them to measure surface temperature with minimum affect to the surface temperature, qualify to be `calibrated' in the accepted sense of the word.

Because there are many thousands of uncompensated surface temperature measuring devices in existence these can not be ignored, and are often sent for `calibration'.

A preferred word to `calibration' for these devices would be `simulation' or `evaluation', ie. we would simulate the normal contact conditions of the surface measuring device.

A few examples will help to explain:

1. If the surface probe is normally used on a smooth flat surface with a smear of grease to aid thermal contact, then the surface of the hotplate should also be smeared with grease, to simulate normal use.

2. If the surface probe is used without thermally conducting liquid, on, for example, the curved rough surface of a cast iron pipe, then a piece of similar material should be placed in the hot plate recess to simulate the actual users situation.

<u>TUTORIAL</u>

Another major factor affecting measurement is airflow and hence stem conduction. Used in windy conditions outside for example, the stem conduction of the surface measuring probe will be many times that of the same probe in still air.

Although, as far as I know, there are no methods written down for contact surface temperature probe calibration, the following should give enough information to evaluate such a probe.

Suggested method of contact surface temperature probe performance evaluation:

1. Set the temperature of the hot plate to the value agreed with the customer.

2. Add any change of surface material supplied by the customer to simulate use.

3. Support the unknown probe vertically onto the surface, using conducting liquid - or not - as agreed with the user. The probes weight should be used to give the necessary contact to the surface.

4. Connect the 944 probe onto the surface close to the unknown probe.

5. Allow time to stabilise and record hot plate controller temperature, 944 temperature and unknown probe temperature. Take a number (n) of readings say $3 \leq n \leq 10$ to obtain the mean value and the deviation from the mean.

6. Move both probes and repeat.

The above tests should be performed in still air.

7. Switch on a fan about 1 metre away from the test apparatus and wait for the system to re-stabilise. Note readings as in 5 and 6 above.

8. Change temperature if required and repeat steps, 5, 6 and 7.

9. The results should give a calibration under stated conditions plus variations in readings due to different user conditions.

NOTE

A proposal by Dr. M. De Groot has been put before the European Community to better define Surface Temperature Measurement. Isothermal Technology is the only UK body involved in this study.

TUTORIAL

APPENDIX 1

SURFACE TEMPERATURES

A surface, because it is the interface between 2 systems, does not have a temperature as such. A user who wants to know temperature should define his measurement problem more exactly. For example:

Is he interested in the amount of heat dissipated by the surface?
How hot the surface feels to the touch - will it burn fingers?
The amount of radiation emitted by the surface?
The temperature of one of the systems near the surface?

Each of these measurement problems has a different answer and each would give a different "surface" temperature for the same surface. In general there are 2 classes of techniques used to measure surface temperature.

NON-CONTACT METHODS

Infrared and optical pyrometers measure the temperature by determining the amount of energy radiated from the surface. Generally the emissivity of the surface needs to be known, though the advent of "two colour" pyrometers allows the temperature to be found without knowledge of the emissivity.

Commonly used mounting techniques for surface thermometers

TUTORIAL

Coloured paints or crayons which change colour at specified temperatures can be applied to the surface as temperature indicators. For many the colour change is irreversible, and they are, therefore, "once only" techniques. They may also change the temperature profile of the surface due to the insulation effects and different emissivities.

Several measurement techniques have been developed that establish a heat balance between the thermometer and the surface. The thermometer is slowly heated to the same temperature as that of the surface, with the only contact between the 2 being through the intervening warm air. These thermometers have found application where large moving surfaces are involved.

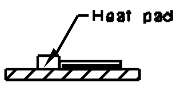
CONTACT METHODS

The problem of obtaining sufficient immersion depth, when surface temperatures are measured, is by itself difficult. When combined with the large temperature gradients usually found on one or both sides of the surface, accurate measurements of surface temperature by contact methods become almost impossible.

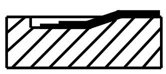
Most surface thermometers are based on thermocouples, PRT's or thermistors.

To obtain a good immersion depth, the thermometer should be "thermally tied" to the surface for several centimetres. Another approach is to bed the thermometer under the surface, ie. approach the surface from the side with the smallest temperature gradients.

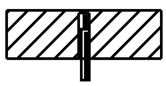
(a) Mounted directly on surface



(b) Use of heat collecting pad



(c) Mounted in groove



(d) Mounted from rear of surface

BIBLIOGRAPHY

1. An older text, still in print, offers a comprehensive look at many industrial temperature measurement problems. It is "Temperature measurement in engineering", by H.D. Baker, E.A. Ryder, and N.H. Baker, Wiley, Vol. 1. 1953, Vol. II 1961.

2. Some more modern development in industrial temperature measurements can be found in "Advances in instrumentation", Proceedings of the ISA Conference held annually.

3. Thermometer applications are covered by articles in TMCSI.

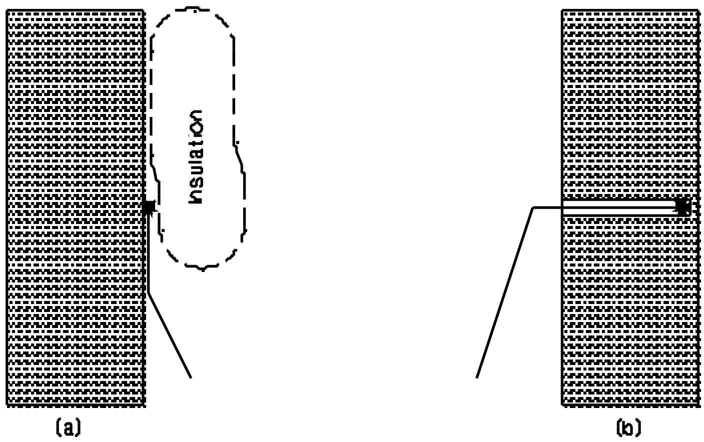
4. British Standards Institute publishes a Code of Practice which is in several parts, not all available, and some are currently in need of revision, but contains much useful information. BS1041 "Code for Temperature Measurement".

TUTORIAL

The most difficult immersion problems occur when making measurements of air and surface temperatures. For air-temperature measurements the effective diameters of probes may be as large as ten times the actual diameter of the probe; a probe requiring 10 diameters immersion in the calibration bath may require more than 100 diameters immersion in air.

The fundamental problem with surface temperature measurements is that, since a surface is an infinitely thin boundary, there is no `system' into which you can immerse the thermometer. With surface-temperature measurements, the answer to the measurement problem often lies in analysing the reason for making the temperature measurement in the first place. For example, if we need to know how much energy the surface is radiating we should use a radiation thermometer; if we want to know the likelihood of the surface posing a human burn risk then we should use a standard finger as specified by a safety standard. Assessment of the uncertainties in surface measurements is also difficult because of the number of sources of error present.

In all cases where immersion errors are suspected it is a very simple matter to vary the



immersion length 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. In some cases it may be practical to estimate the true temperature from a sequence of measurements at different immersions.

Two solutions to the problem of surface temperature measurement: (a) attaching a length of the probe to the surface can approximate immersion. In some cases insulation may be helpful in reducing heat losses by radiation or convection, although it can cause the surface to become hotter; (b) approaching the surface from the side which has the least temperature gradient will give the least error.

TUTORIAL

RADIATION ERRORS AND SHIELDING

Heat can be transferred by any of three mechanisms:

- Conduction - for example, heat is conducted along a metal bar;

- Convection - for example, heat is transferred by the movement of air or other fluids;

- Radiation - for example, heat is radiated by lamps, radiant heaters, and the sun.

Radiation is one of the most insidious sources of error in thermometry. We often fail to recognise the physical connection between the radiant source and the thermometer and overlook it as a source of error. Radiation errors are a particular problem in air and surface thermometry where there is nothing to obscure or shield the source, and where the thermal contact with the object of interest is already weak. Examples of troublesome radiant sources include lamps, boilers, furnaces, flames, electrical heaters and the Sun.

A particularly common problem to watch for is the use of incandescent lamps when reading thermometers. If you must use a lamp, then use a low-power fluorescent lamp which will radiate very little in the infra-red portion of the spectrum.

With more difficult measurements, such as air and surface temperatures, anything at a different temperature which has a line-of-sight to the thermometer is a source of error. This includes cold objects such as freezers which act as radiation sinks and absorb radiation emitted by the thermometer. To put things in perspective, remember that at room temperature anything radiates (and absorbs from its neighbours) about 500 watts per square metre of surface area, so the radiative contact between objects is far greater than we would expect intuitively. In a room near a large boiler a mercury-in-glass thermometer may exhibit an error of several degrees.

There are two basic strategies when you are faced with a measurement that may be affected by radiation. Firstly, remove the source; and secondly, shield the source. Removing the source is obviously the most effective strategy if this is possible. However, the thermometry is very often required in association with the source, particularly in temperature-control applications. In these cases it may be possible to change the source in a way which will give an indication of the magnitude of the error.

TUTORIAL

If you are unable to remove the radiation source then shielding is the only resort. A typical radiation shield is a highly reflective, usually polished, metal tube which is placed over the thermometer. The shield reflects most of the radiation away from the thermometer and itself. The shield will usually reduce the error by a factor of about 3 to 5. The change in the thermometer reading when the shield is deployed will give a good indication of the magnitude of the error and whether more effort is required. Successive shields will help but will not be as effective as the first. Suitable trial shields are clean, shiny metal cans and aluminium foil.

The disadvantage of using a radiation shield in air-temperature measurements is that the movement of air around the thermometer is greatly restricted, further weakening the thermal contact between the air and the thermometer. The problem is compounded if the shield is warmed by the radiation and conducts the heat to the stagnant air inside the shield. Therefore, to be effective the shield must allow free movement of air as much as possible. In some cases a fan may be needed to improve thermal contact by drawing air over the sensor, and to keep the shields cool. Note that the fan should not be used to push the air as the air will be heated by the fan motor and friction from the blades.

FAULT FINDING

The TTI 4 system is maintenance free, servicing should be carried out by qualified personnel only.

The probe by its nature is made from fine wire, and after a lot of use one of these wires may break; most probably in the plug. The length of the cable to the controller is not critical and so a broken wire may be stripped and reconnected.

When a replacement semi standard thermocouple is required the 944 must be returned to Isotech.