



Computer Compatible Radial Heat Conduction Accessory

Instruction Manual

HT12C

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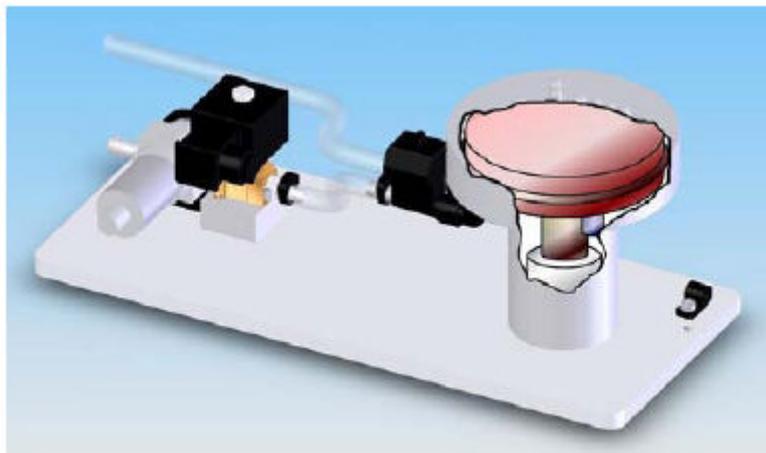
General Overview

This instruction manual should be used in conjunction with the product manual supplied with the 'Computer Compatible Heat Transfer Service Unit'.

The Armfield Computer Compatible Linear Heat Conduction accessory HT12C has been designed to demonstrate the application of the Fourier Rate equation to simple steady-state conduction radially through the wall of a tube. The arrangement, using a solid metal disk with temperature measurements at different radii and heat flow radially outwards from the centre to the periphery, allows the temperature distribution and flow of heat by radial conduction to be investigated.

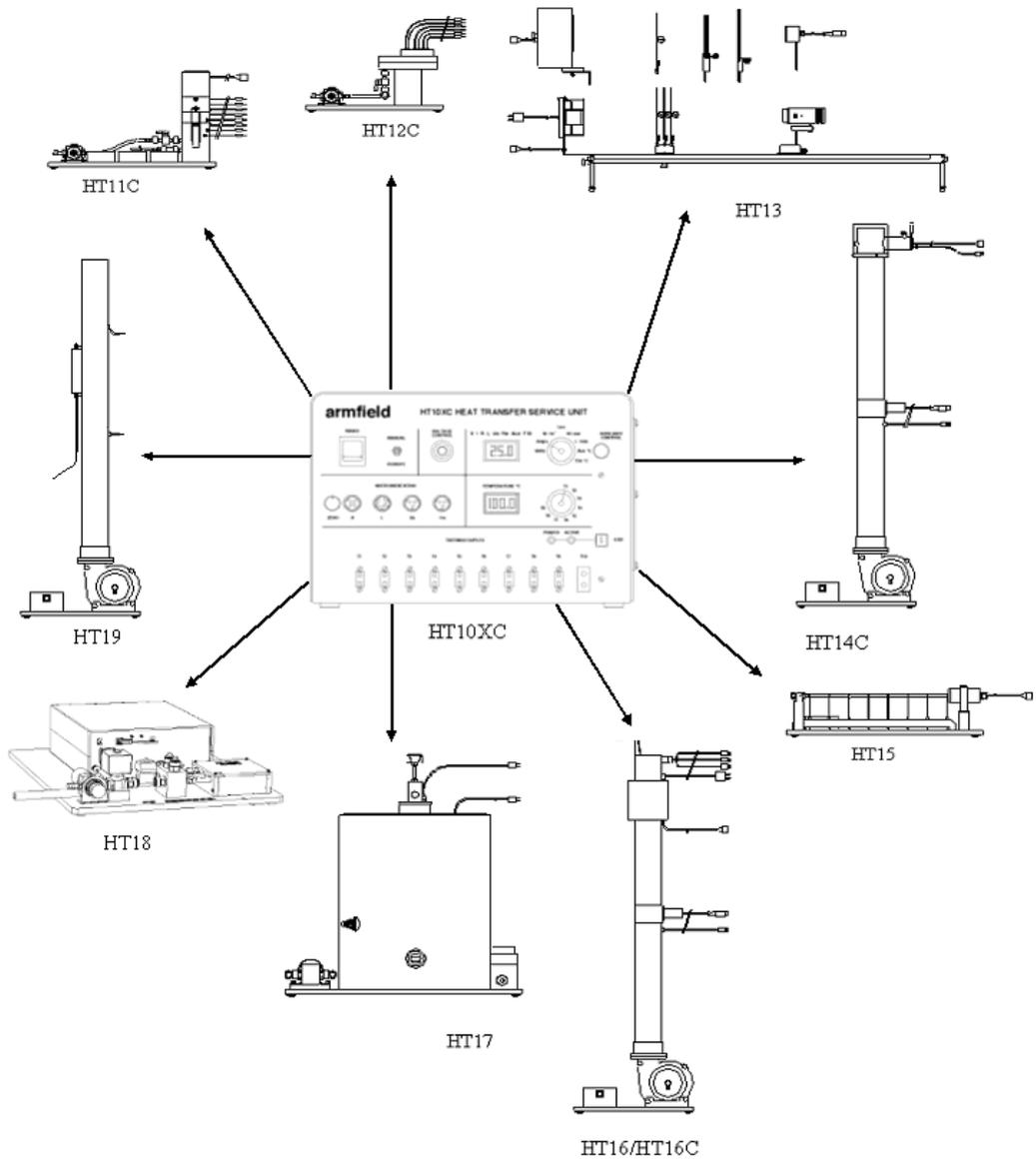
This instruction manual describes the operation of the HT12C Computer Compatible Linear Heat Conduction accessory, which must be used in conjunction with the HT10XC Heat Transfer Service Unit (supplied separately) and may be operated remotely from a Windows™-compatible PC via the USB interface device included within the console. Details of the service unit are given in a separate instruction manual which is supplied with the unit. This manual describes the operation of the HT12C accessory and includes a set of Laboratory Teaching Exercises.

The HT12C is one of a range of seven small scale heat transfer laboratory teaching accessories which demonstrate the basic modes of heat transfer (conduction, convection and radiation). These accessories may be individually connected to a common bench top service unit (HT10XC) which provides the necessary electrical supplies and measurement facilities for investigation and comparison of the different heat transfer characteristics.



The HT12C Computer Compatible Radial Heat Conduction Accessory

HT10XC and accessories



Equipment Diagrams

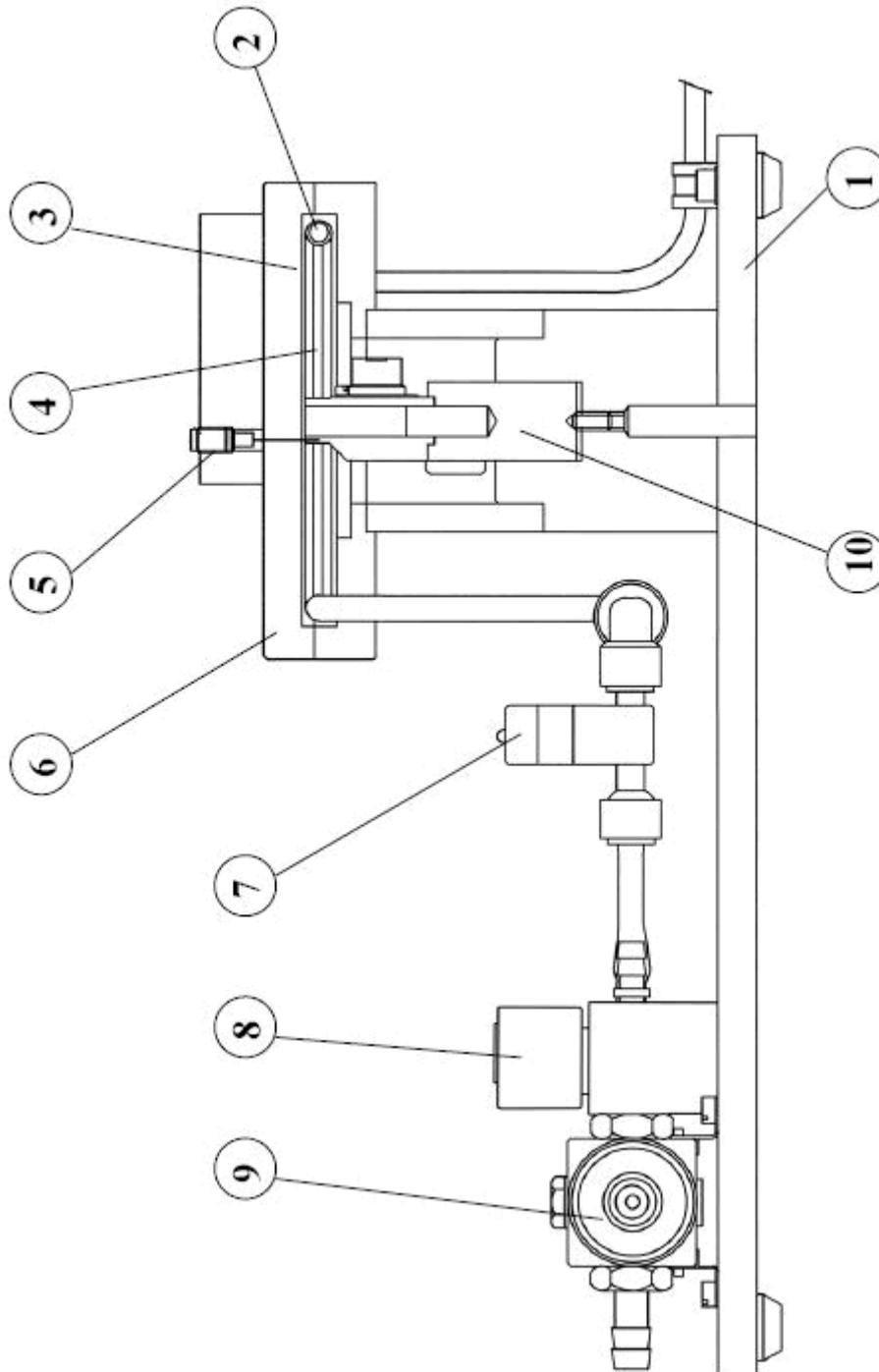


Figure 1: Front View of HT12C Computer Compatible Radial Heat Conduction Accessory

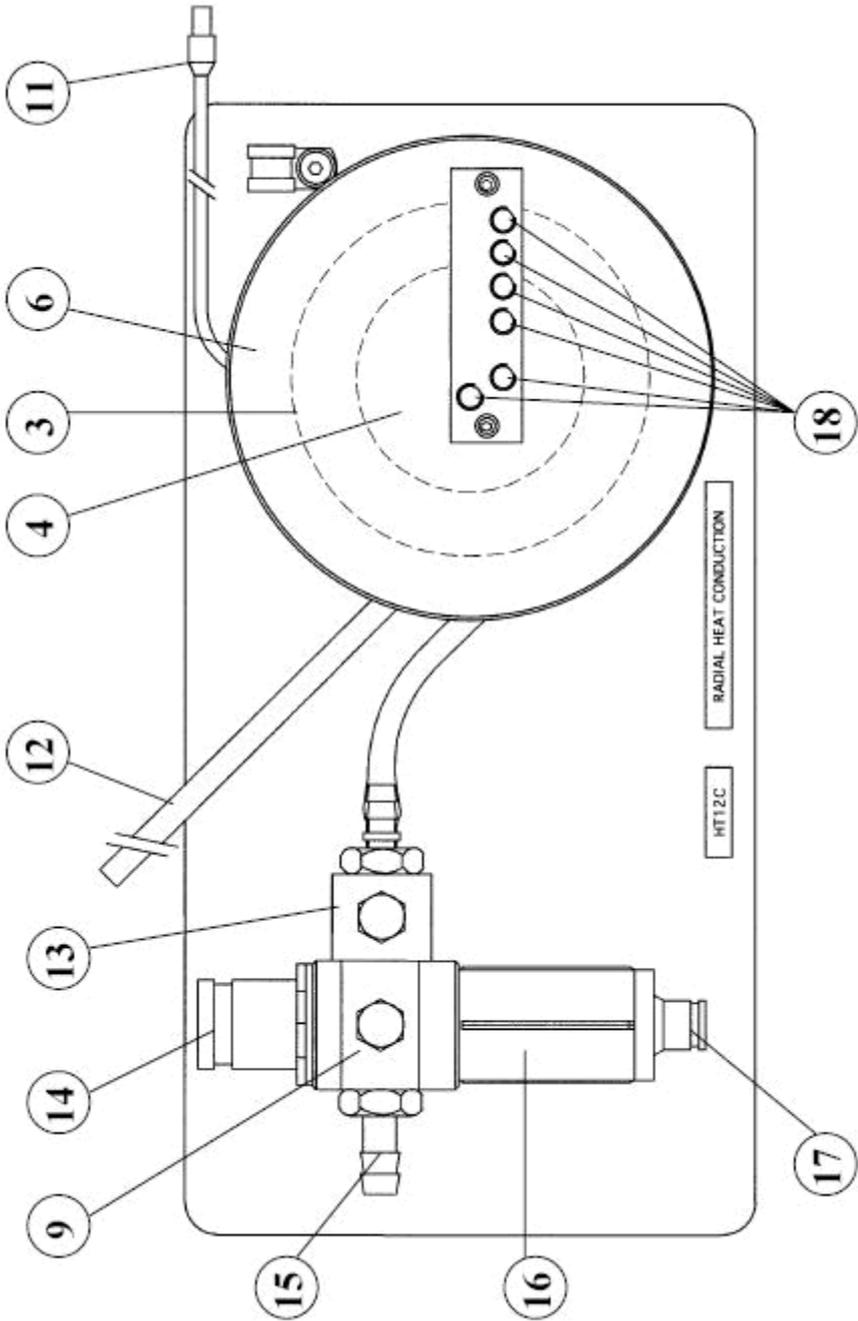


Figure 2: Top View of HT12C Computer Compatible Radial Heat Conduction Accessory

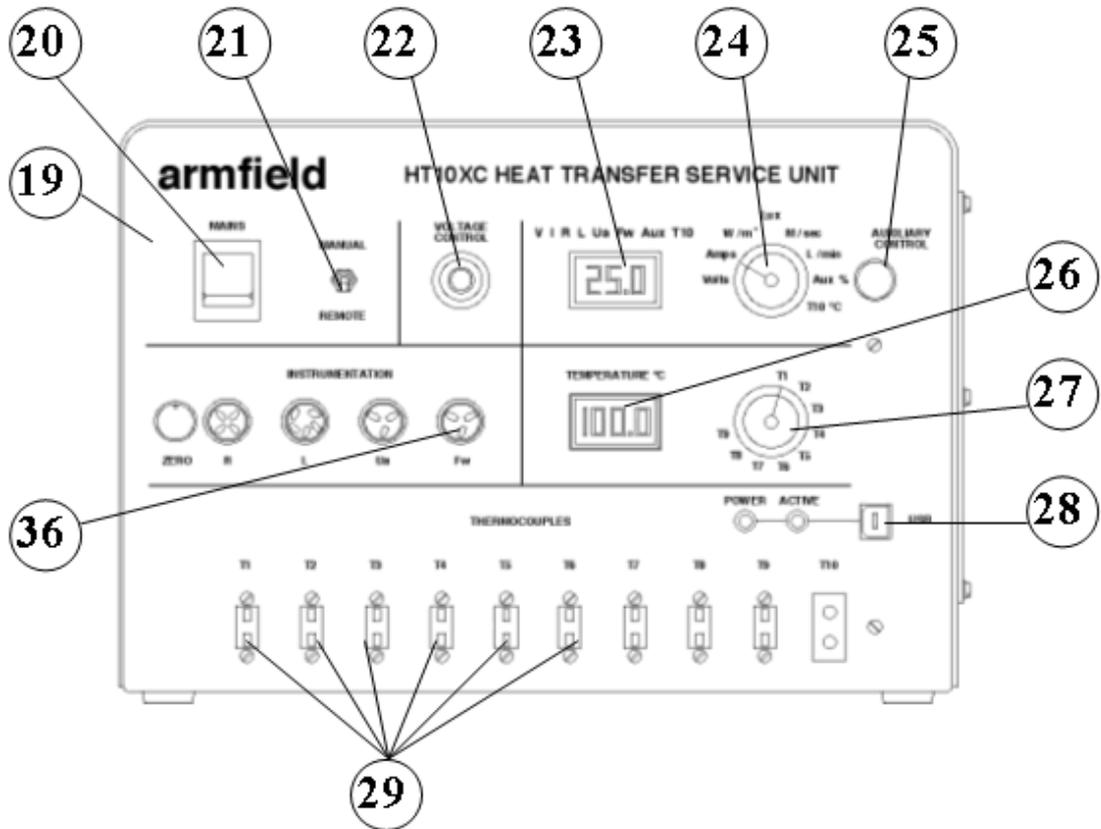


Figure 3: Front View of HT10XC Heat Transfer Service Unit

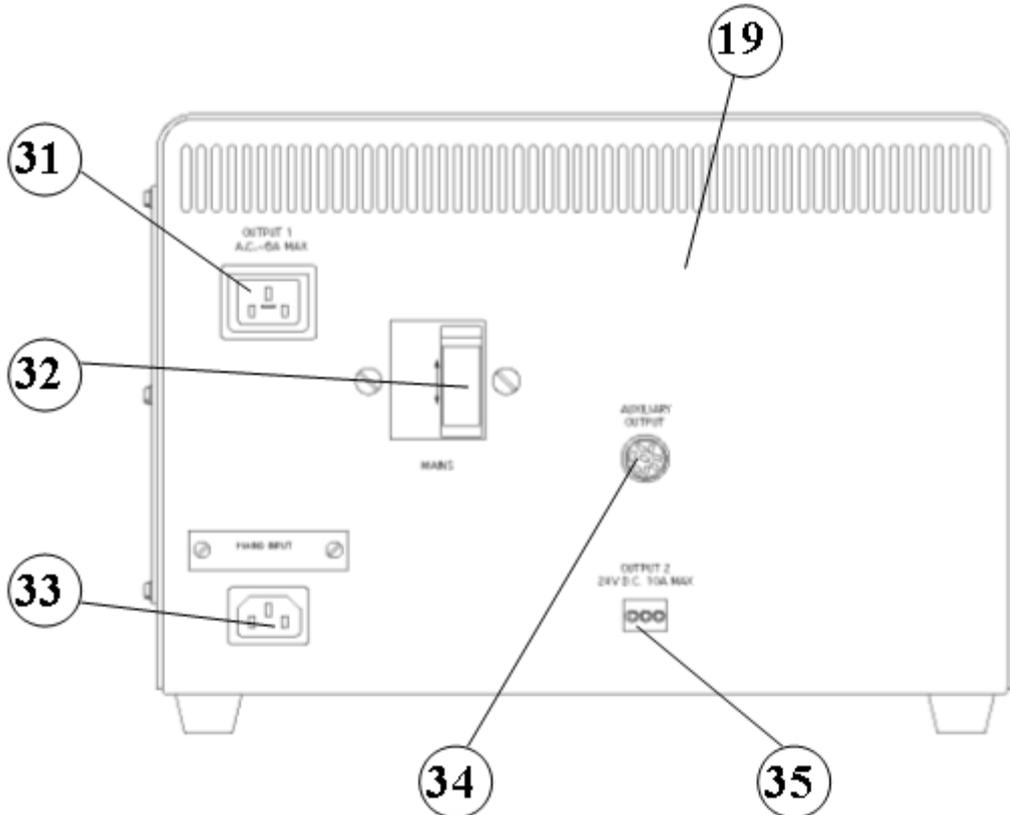


Figure 4: Rear View of HT10XC Heat Transfer Service Unit

Important Safety Information

Introduction

All practical work areas and laboratories should be covered by local safety regulations **which must be followed at all times**.

It is the responsibility of the owner to ensure that all users are made aware of relevant local regulations, and that the apparatus is operated in accordance with those regulations. If requested then Armfield can supply a typical set of standard laboratory safety rules, but these are guidelines only and should be modified as required. Supervision of users should be provided whenever appropriate.

Your **HT12C Radial Heat Conduction Accessory** has been designed to be safe in use when installed, operated and maintained in accordance with the instructions in this manual. As with any piece of sophisticated equipment, dangers exist if the equipment is misused, mishandled or badly maintained.

Water Borne Hazards

The equipment described in this instruction manual involves the use of water, which under certain conditions can create a health hazard due to infection by harmful micro-organisms.

For example, the microscopic bacterium called *Legionella pneumophila* will feed on any scale, rust, algae or sludge in water and will breed rapidly if the temperature of water is between 20 and 45°C. Any water containing this bacterium which is sprayed or splashed creating air-borne droplets can produce a form of pneumonia called Legionnaires Disease which is potentially fatal.

Legionella is not the only harmful micro-organism which can infect water, but it serves as a useful example of the need for cleanliness.

Under the COSHH regulations, the following precautions must be observed:

- Any water contained within the product must not be allowed to stagnate, i.e. the water must be changed regularly.
- Any rust, sludge, scale or algae on which micro-organisms can feed must be removed regularly, i.e. the equipment must be cleaned regularly.
- Where practicable the water should be maintained at a temperature below 20°C. If this is not practicable then the water should be disinfected if it is safe and appropriate to do so. Note that other hazards may exist in the handling of biocides used to disinfect the water.
- A scheme should be prepared for preventing or controlling the risk incorporating all of the actions listed above.

Further details on preventing infection are contained in the publication "The Control of Legionellosis including Legionnaires Disease" - Health and Safety Series booklet HS (G) 70.

Electrical Safety

The equipment described in this Instruction Manual operates from a mains voltage electrical supply. It must be connected to a supply of the same frequency and voltage

as marked on the equipment or the mains lead. If in doubt, consult a qualified electrician or contact Armfield.

The equipment must not be operated with any of the panels removed.

To give increased operator protection, the unit incorporates a Residual Current Device (RCD), alternatively called an Earth Leakage Circuit Breaker, as an integral part of this equipment. If through misuse or accident the equipment becomes electrically dangerous, the RCD will switch off the electrical supply and reduce the severity of any electric shock received by an operator to a level which, under normal circumstances, will not cause injury to that person.

At least once each month, check that the RCD is operating correctly by pressing the TEST button. The circuit breaker **MUST** trip when the button is pressed. Failure to trip means that the operator is not protected and the equipment must be checked and repaired by a competent electrician before it is used.

Hot Surfaces

This apparatus is capable of producing temperatures that could cause **burns / serious burns**.

- Allow time for the equipment to cool before handling any of the components.
- Do not touch any surfaces with a 'Hot Surfaces' warning label.
- Do not allow the apparatus to come into contact with flammable materials or liquids.
- Do not cover or store the equipment until it has cooled.
- Any safety guards are there for operator protection- they must not be removed except as described in this manual, and nothing should be inserted through the guards.
- Always operate the apparatus according to the Operational Procedures described in this manual.
- The apparatus should not be left unattended while switched on.

Hot Liquids

This apparatus contains fluid at temperatures capable of causing serious scalds / scalds.

- Always allow time for the apparatus to cool before disconnecting any tubing.
- Avoid skin contact with hot fluids. Take particular care if refilling of the apparatus or manual collection of the hot fluid is required during use.
- Always operate the apparatus according to the Operational Procedures described in this manual.
- Use only those fluids described in this manual when setting up and operating this equipment.

Description

Where necessary, refer to the drawings in the [Equipment Diagrams](#) section.

Overview

The 'Computer Compatible Radial Heat Conduction' accessory comprises a solid disk of material which is heated at the centre and cooled at the periphery to create a radial temperature difference with corresponding radial flow of heat by conduction.

Details of connections between the HT12C and the HT10XC service unit are given in the Installation section.

Baseplate

The accessory is mounted on a PVC baseplate (1) which stands on the bench top alongside the HT10XC.

Heat Transfer Disk

The disk (3) is manufactured from brass 3.2mm thick and 110mm diameter with a central copper core (4) 14mm diameter. The thermal conductivity of the Brass disk is approximately 125 W/m°C at the typical operating temperatures in the HT12C. The entire radial specimen is located inside a plastic enclosure (6) which provides an air gap and insulates the section to minimise heat loss to the surroundings and prevent burns to the operator.

Heating Element

The central core of the disk is heated by a cartridge type electric heating element (10) which is operated at low voltage for increased operator safety and is protected by a thermostat (5) to prevent damage from overheating. The heating element is rated to produce 100 Watts nominally at 24 VDC. The power supplied to the heating element can be varied and measured using the HT10XC. The lead from the heating element (11) is connected to the DC outlet socket marked OUTPUT 2 on the HT10XC.

Cooling Water

The periphery of the disk is cooled by cold water flowing through a copper tube (2) which is attached to the circumference of the disk. Quick-release connections allow rapid connection of the cooling tube to a cold water supply. A pressure regulator (9) is incorporated to minimise the effect of fluctuations in the supply pressure. A proportioning solenoid valve (8) is powered from the HT10XC console via the AUXILIARY POWER socket (34), and allows the cold water flow rate to be controlled from a compatible PC, or from the service unit HT10XC. The valve has an operating range of 0 - 1.5 litres/min.

Measuring the Cooling Water Flow Rate

A turbine-type flow sensor (7) provides readings of cooling water flowrate directly in units of litres/min when connected to the socket Fw (36) on the HT10XC console. The sensor output may be monitored and recorded using a compatible PC running the Armfield HT12C software, or it may be displayed on the HT10XC console. The sensor has an operating range of 0 - 1.5 litres/min.

Thermocouples

Six type K thermocouples (18) are positioned at different radii in the heated disk to indicate the temperature gradient from the central heated core to the cooled periphery of the disk. Each thermocouple is located in a hole with the thermocouple bead on the centreline of the disk. The first thermocouple is located in the edge of the copper heated core at a radius of 7mm. The remaining thermocouples are located at uniform intervals of 10mm from the centre of the disk. The thermocouples are positioned on a tangent to the central heated core to minimise the disturbance to the heat flow between the thermocouples. The thermocouples are effectively positioned at the following radii from the centre of the disk:

T1	7mm
T2	10mm
T3	20mm
T4	30mm
T5	40mm
T6	50mm

Each thermocouple is fitted with a miniature plug for direct connection to the HT10XC service unit (29).

Installation

Advisory

Before operating the equipment, it must be unpacked, assembled and installed as described in the steps that follow. Safe use of the equipment depends on following the correct installation procedure.

Where necessary, refer to the drawings in the [Equipment Diagrams](#) section.

Note: The HT12C 'Computer Compatible Radial Heat Conduction' accessory must be used in conjunction with the HT10XC 'Computer Compatible Heat Transfer Service Unit'. This Installation Guide assumes that the HT10XC has already been installed according to the guide included with the HT10XC manual.

Electrical supply

	HT12C-A	HT12C-B	HT12C-G
Green/yellow lead	Earth (Ground)	Earth (Ground)	Earth (Ground)
Brown lead	Live (Hot)	Live (Hot)	Live (Hot)
Blue lead	Neutral	Neutral	Neutral
Fuse rating	13A	15A	13A
Voltage	220-240V	110-120V	220V
Frequency	50Hz	60Hz	60Hz

Installing the optional PC software

If it is required to operate HT12C using the optional software supplied with HT10XC then it will be necessary to install the software from the CD-ROM supplied with HT10XC onto an appropriate PC (PC not supplied).

For instructions on how to install and run the software insert the CD-ROM into the optical drive on the PC (PC not supplied) then choose 'Help' from the menu.

After installing and running the software on the PC, instructions on how to operate the software can be obtained by choosing the 'Help' tab in the top right hand corner of the screen as shown below:



Note that when operating the software for the first time it will be necessary to enable the USB virtual COM port by choosing the Red telephone icon (Start COM session).



Full instructions about enabling the port are included in the Help menus.

Installing the Equipment

- Place the HT12C on a suitable bench top beside the HT10XC service unit.
- Ensure that the mains on/off switch (20) on the front of the service unit is in the OFF position.
- Connect the miniature thermocouple plugs from each of the six temperature sensors (18) to the appropriate socket (29) on the front of the service unit, ensuring that the numbers on the plugs and sockets are compatible.
- Set the Voltage Control potentiometer (22) on the front of the service unit to zero (release the clamp and turn the adjusting knob fully anticlockwise).
- Set the REMOTE/MANUAL selector switch (21) to the MANUAL position.
- Connect the power lead (11) from the heater inside the HT12C to the variable DC outlet socket marked OUTPUT 2 (35) at the rear of the service unit.
- Connect the cold water flow control valve (13) to the socket marked AUXILIARY CONTROL (34) on the HT10XC console.
- Connect the cold water flow rate sensor (7) to the socket marked Fw (36) on the HT10XC console.
- Ensure that the cold water pressure regulating valve (9) is fully off by pulling the knob (14) outwards away from the body of the regulator, then turning the knob fully anticlockwise. Ensure that the drain/vent (17) on the transparent filter bowl is closed by turning it fully clockwise.
- Connect a supply of clean cold water to the inlet (15) on the HT12C using suitable flexible tubing. Secure the tubing to the inlet connection on the pressure regulator. A flow of 1.5 litres/minute is required at a maximum pressure of 1 bar gauge.
- Direct the flexible outlet tubing (12) attached to the cooling tube around the periphery of the heated disk to a suitable drain for the cooling water exiting the accessory.
- (HT12 with optional flow sensor SFT2 only: if the optional flow sensor SFT2 is used, connect the flow sensor to the outlet tubing (12) on the HT12C using the quick release connector. Connect the electrical lead from the flow sensor to the socket marked Fw on the front of the service unit).

- Ensure that the HT10XC service unit is connected to a suitable mains supply, as described in the HT10XC manual. Switch on the power supply to the console.
- Ensure that the RCD/RCCB (32) at the rear of the service unit is in the ON (up) position.
- Set the mains on/off switch (20) on the service unit front panel to the ON position.
- Observe that both digital panel meters (23, 26) are illuminated (as no power is supplied to the accessory at this stage the temperature display should indicate approximately ambient temperature).
- Set the upper display panel selector switch to L/min. Open the cold water flow control valve (7) fully by turning the AUXILIARY CONTROL knob (25) fully clockwise.
- Gradually open the pressure regulating valve (9) by turning the knob (14) clockwise until the cold water flow through the cooling section is approximately 1.5 litres/min as indicated on the upper display panel. (If using the HT12 without the flow sensor SFT2 then the flow rate may be calculated using a measuring beaker to catch the exiting flow, and a stopwatch, to perform a timed volume collection).
- When the flowrate is acceptable push the knob on the regulator in to lock the setting of the pressure regulator.
- Set the temperature selector switch (27) to position T1 to indicate the temperature at the centre of the heated disk. Check that the temperature indicated is approximately ambient temperature.
- Set the upper display panel selector switch (24) to position V to indicate the voltage supplied to the heating element on HT12C. Adjust the Voltage Control potentiometer (22) to give a reading of approximately 12 Volts on the display (ensure that the clamp on the side of the knob is released before turning the knob).
- Check that the reading of temperature T1 gradually increases. Check that temperature T1 stabilises. Check that the temperatures indicated decrease towards the cooled periphery of the disk, i.e. $T1 > T2$, $T2 > T3$, $T3 > T4$, $T4 > T5$ and $T5 > T6$ by selecting each position in turn on the selector switch.
- If required, install the HT12C software:
 - Insert the software CD-ROM into the CD or DVD drive on the PC
 - The CD should autorun. If autorun fails to initiate, select 'Run...' from the 'Start' menu, and type 'D:\setup.exe' where 'D' is the letter of your CD-ROM drive. (ignore the " marks).
 - Follow the instructions on the screen
 - You will need to restart the PC before running the software
 - Connect the HT10XC console to the PC using the USB cable provided to connect the console socket (28) to a free USB port.

Note: The software must be installed BEFORE connecting the console in order to provide the operating system with the correct USB driver. If the console is been connected before installing the software, Windows may install the wrong driver. If this happens, ask your system administrator to delete the installed USB driver for the HT10XC console, then re-install the software before reconnecting the console.

- Run the HT12C software and select the Project Work exercise.
- Observe the sensor displays on the mimic diagram screen. They should indicate similar values to those on the console displays (they may not match exactly as the sensor response may not be completely linear and sensor calibration may therefore differ slightly across the sensor range). If desired, the software may be calibrated to match the console display exactly, by following the instructions provided in the software Help Text.
- Turn off the power to the heater by setting the potentiometer to zero.
- If using the software, observe that the temperatures on the mimic diagram display reduce as the disk cools.
- Allow the disk to cool completely, then turn off the cooling water.

Note: Although a thermostat is incorporated to protect the heating element from over heating it is good practice to turn off the power first followed by the cooling water.

- If using a computer, observe that the cooling water flow rate indicated on the mimic diagram display drops to zero.

The basic operation of the 'Radial Heat Conduction' accessory and 'Heat Transfer Service Unit' has been confirmed. Refer to the Operation section for further information.

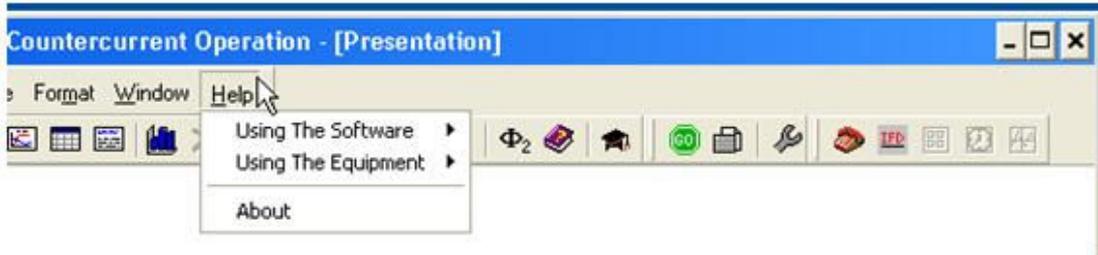
Operation

Where necessary, refer to the drawings in the [Equipment Diagrams](#) section.

The apparatus must be set up in accordance with the Installation section. Additionally, ensure you have read the Important Safety Information at the beginning of this manual.

Operating the optional PC software

Details about operating the optional HT12C software can be obtained by choosing the 'Help' tab in the top right hand corner of the screen as shown below:



Operating the Equipment

Setting the Heater Voltage

The heater voltage may be set using the HT12C software by typing the voltage required into the relevant display box on the mimic diagram screen, or by using the up and down arrows next to the display box. The Manual/Remote selector switch (21) should be set to REMOTE during normal computer operation. The heater may also be operated manually using the console, when the selector switch should be set to the MANUAL position. This allows the voltage supplied to the heater to be adjusted using the multi-turn potentiometer (22) marked VOLTAGE CONTROL.

The range of the output voltage is continuously adjustable from 0 Volts to 24 Volts DC.

Monitoring the Heater Voltage

The heater voltage is displayed in the HT12C software on the mimic diagram screen. The Manual/Remote selector switch (21) should be set to REMOTE during normal computer operation. The voltage supplied to the heater can also be monitored by setting the top measurement selector switch (24) to position V while the manual/remote selector switch (21) is set to MANUAL. The reading is displayed directly in Volts on the software screen (remote operation) or on the top console display panel (23) (manual operation).

Monitoring the Heater Current

The current drawn by the heater in the accessory can be monitored within the HT12C software on the mimic diagram screen. The Manual/Remote selector switch (21) should be set to REMOTE during normal computer operation. The current may also be monitored by setting the top measurement selector switch (24) to position I while the remote/manual selector switch is set to MANUAL. The reading is displayed directly in Amps on the software screen (remote operation) or on the top console display screen (23) (manual operation).

As the electrical supply to the heater is Direct Current the power supplied to the heater is simply obtained from the product of the Voltage and Current i.e.

$$\text{Heater Power } Q = \text{Voltage } V \times \text{Current } I$$

e.g. If $V = 15.0$ Volts and $I = 2.00$ Amps then $Q = 2 \times 15 = 30.0$ Watts

Note: The heated core of HT12C incorporates a thermostat to limit the maximum operating temperature. If the heater voltage is set too high, resulting in excessive temperature, the current to the heater will be disconnected until the thermostat resets when the temperature falls. If the display shows no current when voltage is applied to the heating element check that temperature T1 is below 100°C.

If temperature T1 is excessive ensure that cooling water is flowing through the cooling tube to drain. If temperature T1 does not reduce set the Heater Voltage to zero and allow the thermostat to reset.

If temperature T1 is not excessive but the display shows no current when voltage is applied to the heating element check the following:

Check that RCD at the rear of the service unit (32) is in the up position.

Check that the heater lead (11) on the HT12C is connected to the socket marked OUTPUT 2 (35) at the rear of the service unit.

Measuring the Temperatures

The output from any of the six thermocouples T1 to T6 installed on the HT12C (18) can be monitored within the HT12C software on the mimic diagram screen. The Manual/Remote selector switch (21) should be set to REMOTE during normal computer operation. The temperatures may also be monitored during manual operation with the manual/remote selector switch set to MANUAL: Set the temperature selector switch (27) to the required position and read the corresponding value on the lower panel meter (26). All temperatures on the HT12C are indicated with a resolution of one decimal place.

Setting the Cold Water Pressure Regulator

Before using the cooling water system it will be necessary to adjust the pressure regulating valve.

Ensure that the cold water pressure regulating valve (9) is fully off by pulling the knob (14) away from the body of the regulator then turning the knob fully anticlockwise. Ensure that the drain/vent (17) on the transparent filter bowl (16) is closed by turning it fully clockwise.

Connect the cold water flow control valve (13) to the AUXILIARY POWER socket on the rear of the HT10XC console (34). Open the cold water flow control valve fully. The valve may be controlled from a connected computer by typing the required value into the relevant display box on the mimic diagram screen, or by using the up and down arrows next to the box. The Manual/Remote selector switch (21) should be set to REMOTE during normal computer operation. The valve may also be controlled during MANUAL operation using the AUXILIARY CONTROL potentiometer (25).

Gradually open the pressure regulating valve by turning the knob (14) clockwise until the cold water flow through the cooling section is approximately 1.5 litres/min (See Measuring the Cooling Water Flow Rate below).

When the flowrate is acceptable push the knob down to lock the setting of the pressure regulator.

If it is required to reduce the cooling water flowrate adjust the flowrate using the flow control valve (13). Do not use the pressure regulating valve to adjust the flow of cooling water.

Measuring the Cooling Water Flowrate

The lead from the cold water flow meter (7) should be connected to the socket marker Fw on the front of the HT10XC console (36). During computer control (the console selector switch (21) set to REMOTE) the flow rate may be monitored on the software screen. During MANUAL operation the flowrate can be read on the top panel meter (23) with the selector switch (24) set to position Fw.

Equipment Specifications

Overall dimensions (not including service unit)

Height - 185mm

Width - 350mm

Depth - 175mm

USB Channel Numbers

The channel numbers for the USB port are listed below for information:

Channel No	Signal Function
Analog Outputs (0-5 V dc exported from socket):	
Ch 0 Signal	Temperatures T1 to T6 via analog switch Temperatures T1 - T6 (0 - 133°C) Note: T7-T12 not used with HT12
Ch 0 Return	
Ch 1 Signal	Cold water flow control valve (0 - 24 Volts DC)
Ch 1 Return	
Ch 2 Signal	Current to heater I (0 - 10 Amps)
Ch 2 Return	
Ch 3 Signal	Not used with HT12C
Ch 3 Return	
Ch 4 Signal	Not used with HT12C
Ch 4 Return	
Ch 5 Signal	Not used with HT12C
Ch 5 Return	
Ch 6 Signal	Flowrate of water Fw (0 - 1.5 l/min) (On HT12C only unless using optional sensor SFT2)
Ch 6 Return	Not used

Analog Inputs (0-5V dc input from socket):	
DACO Signal	Voltage output V (Remote operation of 0 - 24 Volts)
DACO Ground	Not Used
Digital Outputs (0-5V dc):	
Not Used	
Digital Inputs (0-5V dc):	
Ch 0	Analog switch
Ch 1	Analog switch
Ch 2	Analog switch
Ch 3	Analog switch
Digital ground	
Ch 4 Inhibit analog switch	Not used
Digital ground	Not used

Environmental Conditions

This equipment has been designed for operation in the following environmental conditions. Operation outside of these conditions may result reduced performance, damage to the equipment or hazard to the operator.

- a. Indoor use;
- b. Altitude up to 2000m;
- c. Temperature 5°C to 40°C;
- d. Maximum relative humidity 80% for temperatures up to 31°C, decreasing linearly to 50% relative humidity at 40°C;
- e. Mains supply voltage fluctuations up to $\pm 10\%$ of the nominal voltage;
- f. Transient over-voltages typically present on the MAINS supply;

NOTE: The normal level of transient over-voltages is impulse withstand (over-voltage) category II of IEC 60364-4-443;

- g. Pollution degree 2.

Normally only nonconductive pollution occurs.

Temporary conductivity caused by condensation is to be expected.

Typical of an office or laboratory environment

Routine Maintenance

Responsibility

To preserve the life and efficient operation of the equipment it is important that the equipment is properly maintained. Regular maintenance of the equipment is the responsibility of the end user and must be performed by qualified personnel who understand the operation of the equipment.

General

The equipment should be disconnected from the electrical supply when not in use.

Water should be drained from the equipment before storage.

Draining the Cooling Water Pipework

Water should be drained from the cooling section of the HT12C after use to minimise build up of scale or fouling inside the cooling section. The water can be drained by simply disconnecting the top flexible tube from the outlet to the flow control valve and allowing the water to flow out through the outlet tube under gravity, ensuring that the valve is fully open. To remove the ferrule from the control valve depress the collar on the valve while pulling the ferrule. To reassemble simply push the ferrule fully into the control valve.

Cleaning the Pressure Regulator Filter

The pressure regulator (9) incorporates an integral filter to prevent particles or fibres in the water from entering the delicate regulator. The transparent bowl (16) allows the condition of the filter element to be inspected. Any contamination in the bowl or on the filter should be removed by unscrewing the transparent bowl and rinsing the bowl and element in clean water before reassembling.

RCD Test

Test the RCD (32) by pressing the TEST button at least once a month. If the RCD button does not trip when the Test button is pressed then the equipment must not be used and should be checked by a competent electrician.

Laboratory Teaching Exercises

Index to Exercises

[Exercise A - Radial temperature distribution for steady state conduction](#)

[Exercise B - Use of the Fourier Rate Equation and Thermal Conductivity](#)

[Exercise C - Unsteady State Conduction](#)

[Project Work](#)

Nomenclature

Name	Symbol	SI Unit
Inner radius of disk	Ri	m
Outer radius of disk	Ro	m
Radius from centre of disk to thermocouple	Ra (eg. R1)	m
Thickness of disk (distance)	x	m
Voltage to heating element	V	V
Current to heating element	I	A
Electrical power to heating element	Q	W
Heat transfer rate per unit time (heat flow)	Q	W
Temperature measured	Ta (eg. T1)	°C
Thermal conductivity	k	W/m°C
Flow of cooling water (if SFT2 is fitted)	Tw	l/min
Time	t	Secs

Note: The electrical power Q supplied to the heated core of the disk by the heating element is assumed to be the same as the heat transfer rate per unit time Q radially outwards through the disk, i.e. heat loss to the surroundings is negligible.

Exercise A - Radial temperature distribution for steady state conduction

Objective

To measure the temperature distribution for steady-state conduction of energy through the wall of a cylinder (radial energy flow) and demonstrate the effect of a change in heat flow.

Method

By measuring the change in temperature with radius resulting from the radial conduction of heat, from the heated centre of a disk to the cooled periphery, at different rates of heat flow through the disk.

Equipment Required

HT10XC Heat Transfer Service Unit

HT12C Computer Compatible Radial Heat Conduction Accessory

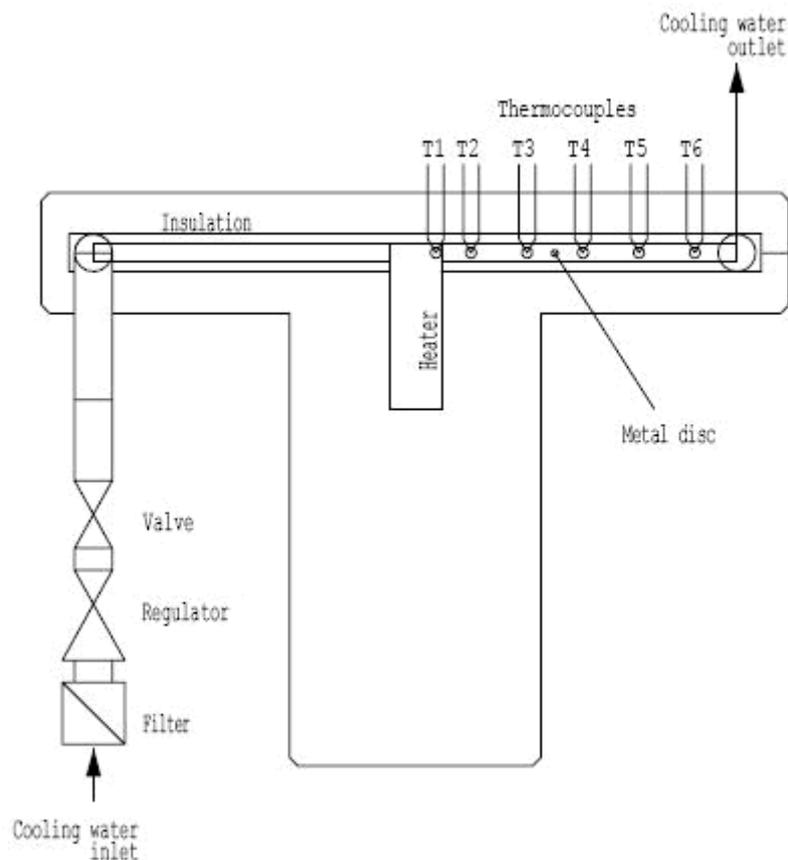
Or

HT12 Radial Heat Conduction Accessory

Optional Equipment

SFT2 Flow Sensor (if using HT12 instead of HT12C)

Equipment set-up



Before proceeding with the exercise ensure that the equipment has been prepared as follows:

Locate the HT12C Radial Heat Conduction accessory (1) alongside the HT10XC Heat Transfer Service Unit (19) on a suitable bench.

Connect the six thermocouples on the HT12C (18) to the appropriate sockets on the front of the service unit HT10XC (29). Ensure that the labels on the thermocouple leads (T1 - T6) match the labels on the sockets.

On the console, set the VOLTAGE CONTROL potentiometer (22) to minimum (anticlockwise) and the REMOTE/MANUAL selector switch (21) to MANUAL, then connect the heater lead from the HT12C (11) to the socket marked Output 2 at the rear of the service unit (35).

Connect the cold water flow control valve (13) to the socket marked AUXILIARY CONTROL (34) on the HT10XC console.

Connect the cold water flow rate sensor (7) to the socket marked Fw (36) on the HT10XC console.

If using a computer to operate the accessory, set the REMOTE/MANUAL selector switch on the console (21) back to REMOTE.

Ensure that a cold water supply is connected to the inlet of the pressure regulating valve on HT12C (15). The water supply should be on.

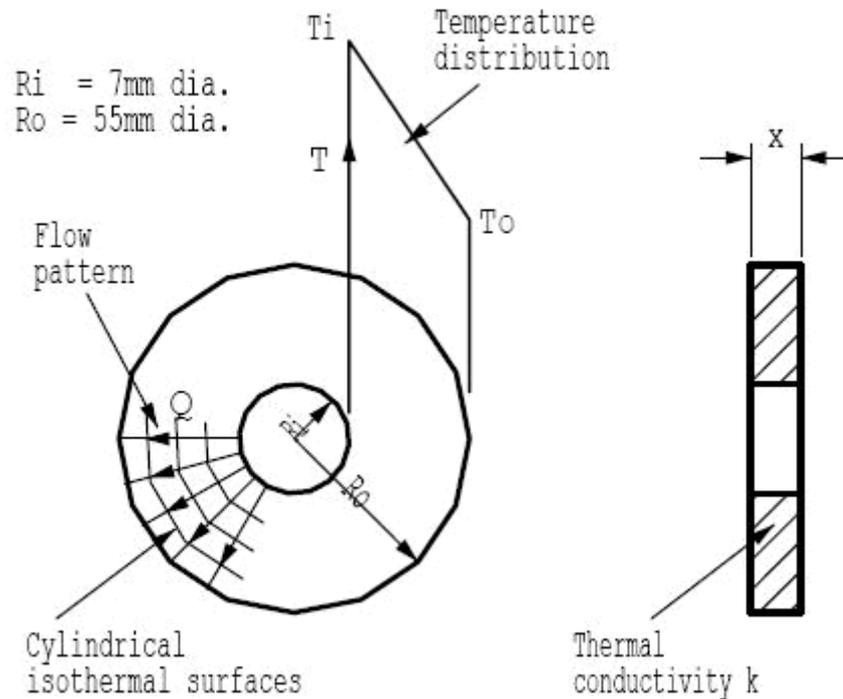
Ensure that the flexible cooling water outlet tube is directed to a suitable drain.

(If using the HT12 with the optional flow sensor SFT2, instead of the HT12C, connect the sensor to the outlet of the HT12C using the quick release connector. Ensure that the flow arrow on the body of the sensor points towards the drain.)

Ensure that the service unit is connected to an electrical supply.

Theory/Background

When the inner and outer surfaces of a thick walled cylinder are each at a different uniform temperature, heat flows radially through the cylinder wall.



The disk can be considered to be constructed as a series of successive layers.

From continuity considerations the radial heat flow through each of the successive layers in the wall must be constant if the flow is steady but since the area of the successive layers increases with radius, the temperature gradient must decrease with radius.

The radial specimen in the HT12C consists of a disk 3.2 mm thick (x) with inside radius $R_i = 7\text{ mm}$ and outside radius $R_o = 55\text{ mm}$.

The object of this exercise is to show the temperature profile resulting from the radial flow of heat outwards from the centre of the disk at different rates of heat flow.

The application of Fouriers Law to calculate the heat flow through the wall and its relationship with radius, thickness and thermal conductivity of the material will be investigated in exercise HT12CB.

Procedure

(Refer to the Operation section if you need details of the instrumentation and how to operate it.)

Switch on the MAINS switch (21). (If the panel meters do not illuminate check the RCD at the rear of the service unit (35), the switch should be up.)

If using a computer, check that the software indicates IFD OK in the bottom right hand corner of the software window.

Adjust the cooling water flow control valve to give approximately 1.5 litres/min. If using a computer, adjust the valve using the control box on the mimic diagram. If operating the equipment manually using the HT10XC console, set the upper display selector switch to L/min and observe the upper display panel while adjusting the AUXILIARY CONTROL knob.

Set the Heater Voltage to 12 Volts. If using a computer, adjust the voltage using the control box on the mimic diagram. If operating the equipment manually using the HT10XC console, set the upper display selector switch to V (volts) and observe the upper display panel while adjusting the AUXILIARY CONTROL knob.

Allow the HT12C to stabilise. If using a computer, monitor the temperatures on the mimic diagram. If using the console, monitor the temperatures using the lower selector switch/meter (27/26).

When the temperatures are stable, select the  icon if using the computer to take a set of results, or manually record the following if using the console:

T1, T2, T3, T4, T5, T6, V, I, Fw*

(*Fw will not be available with the HT12 unless the optional flow sensor SFT2 is fitted).

Set the Heater Voltage to 17 Volts.

Allow the HT12C to stabilise then repeat the above readings.

Set the Heater Voltage to 21 Volts.

Allow the HT12 to stabilise then repeat the above readings.

Set the Heater Voltage to 24 Volts.

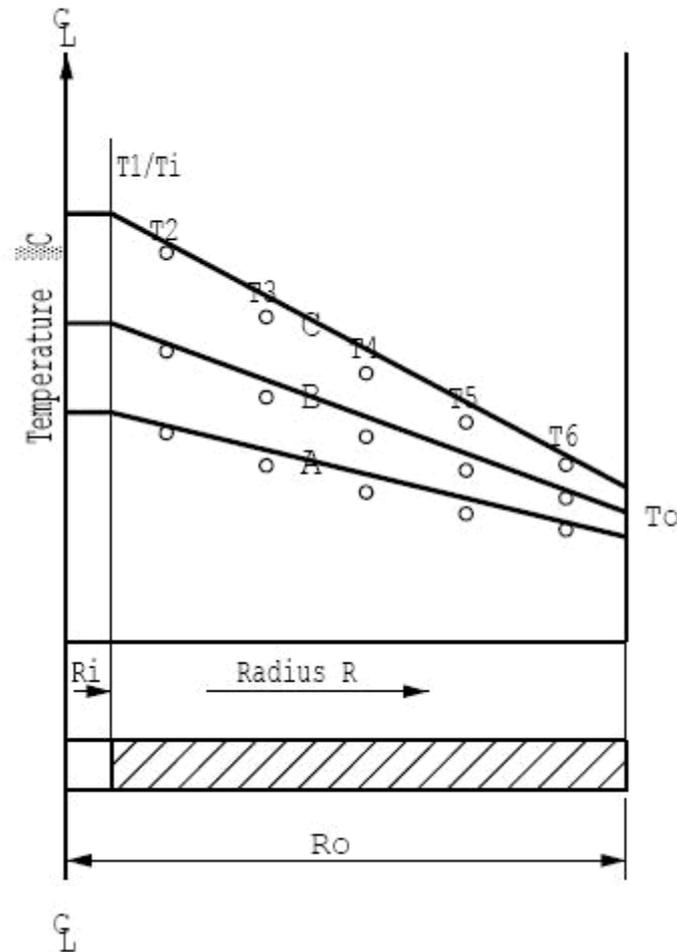
Allow the HT12C to stabilise then repeat the above readings.

Results and Calculations

For this exercise the raw data is tabulated under the following headings:

Heater Voltage	V	Volts
Heater Current	I	Amps
Temperature at 7 mm radius (inside)	T1	(°C)
Temperature at 10 mm radius	T2	(°C)
Temperature at 20 mm radius	T3	(°C)
Temperature at 30 mm radius	T4	(°C)
Temperature at 40 mm radius	T5	(°C)
Temperature at 50 mm radius (outside)	T6	(°C)
Cooling water flowrate	Fw	(l/min) If sensor SFT2 is fitted.

You should also estimate and record the experimental errors for these measurements.



For each set of readings plot a graph of temperature against radius and draw a smooth curve through the points. Your graph should be similar to the diagram above.

Observe that each temperature profile is a curve and that the gradient at any point on the curve decreases with increasing radius from the heated centre.

Observe that the gradient at any radius increases with increasing heat flow.

From your graphs estimate the temperature at the periphery of the disk T_o (at radius $R_o = 55\text{mm}$) for each heat flow Q .

Conclusions

You have demonstrated how heat flow radially through a thick walled cylinder creates a curved temperature profile with the gradient reducing with increasing radius from the centre.

Comment on the change in T_1 when the heat flow through the disk is changed. The consequence of these changes will be investigated in Exercise B.

Note: Exercise B should be carried out on the completion of this exercise.

Exercise B - Use of the Fourier Rate Equation and Thermal Conductivity

Objective

To understand the use of the Fourier Rate Equation in determining the rate of heat flow for steady-state conduction of energy through the wall of a cylinder (radial energy flow) and using the equation to determine the constant of proportionality (the thermal conductivity k) of the disk material.

Method

By measuring the change in temperature between the inside radius (heated) and outside radius (cooled) of the disk at different rates of heat flow through the disk.

Note: If results are available from Exercise A then this exercise can be completed using those results. Refer to the Theory section of this exercise followed by the Results and Calculations. The following instructions apply if results are not available.

Equipment Required

HT10XC Heat Transfer Service Unit

HT12C Computer Compatible Radial Heat Conduction Accessory

Or

HT12 Radial Heat Conduction Accessory

Optional Equipment

SFT2 Flow sensor (if using HT12 instead of HT12C)

Equipment set-up

Before proceeding with the exercise ensure that the equipment has been prepared as follows:

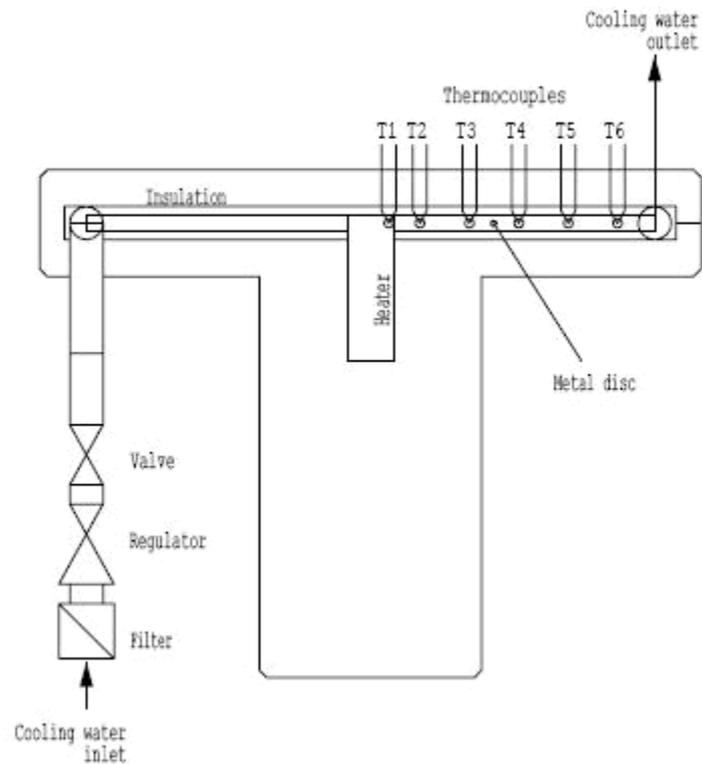
Locate the HT12C Radial Heat Conduction accessory (1) alongside the HT10XC Heat Transfer Service Unit (19) on a suitable bench.

Connect the six thermocouples on the HT12C (18) to the appropriate sockets on the front of the service unit HT10XC (29). Ensure that the labels on the thermocouple leads (T1 - T6) match the labels on the sockets.

On the console, set the VOLTAGE CONTROL potentiometer (22) to minimum (anticlockwise) and the REMOTE/MANUAL selector switch (21) to MANUAL, then connect the heater lead from the HT12C (11) to the socket marked Output 2 at the rear of the service unit (35).

Connect the cold water flow control valve (13) to the socket marked AUXILIARY CONTROL (34) on the HT10XC console.

Connect the cold water flow rate sensor (7) to the socket marked Fw (36) on the HT10XC console.



If using a computer to operate the accessory, set the REMOTE/MANUAL selector switch on the console (21) back to REMOTE.

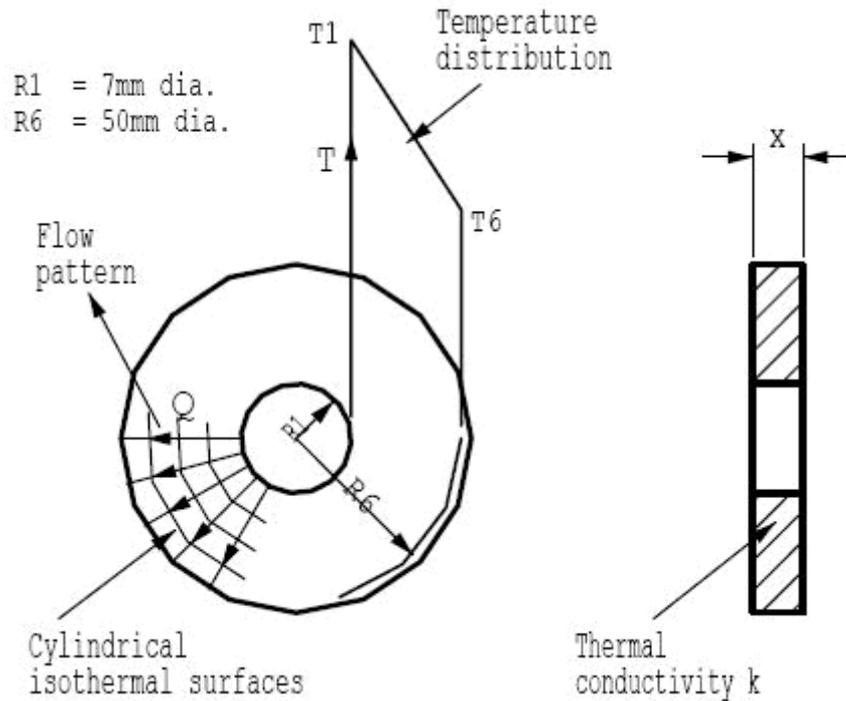
Ensure that a cold water supply is connected to the inlet of the pressure regulating valve on HT12C (15). The water supply should be on.

Ensure that the flexible cooling water outlet tube is directed to a suitable drain.

(If using the HT12 with the optional flow sensor SFT2, instead of the HT12C, connect the sensor to the outlet of the HT12C using the quick release connector. Ensure that the flow arrow on the body of the sensor points towards the drain.)

Ensure that the service unit is connected to an electrical supply.

Theory/Background



From Exercise A it is clear that when the inner and outer surfaces of a cylinder are each at a different uniform temperature, heat flows radially through the wall of the cylinder.

The disk can be considered to be constructed as a series of successive layers.

From continuity considerations the radial heat flow through each of the successive layers in the wall must be constant if the flow is steady but since the area of the successive layers increases with radius, the temperature gradient must decrease with radius.

If a concentric layer (of thickness dR and radius R from the centre) in the wall of the cylinder is considered, the area of heat flow is $2\pi R$ for a unit length of cylinder.

The temperature gradient normal to the axis of the cylinder is dT/dR .

According to Fourier's law:

$$Q = -2\pi R k (dT/dR)$$

Since Q is independent of R , integration gives:

$$Q \ln(R6/R1) = - 2\pi k (T6 - T1) \text{ for heat flow through a unit length of the cylinder}$$

(where $R1$ is the inside radius with corresponding temperature $T1$ and $R6$ is an outer radius corresponding to temperature $T6$).

Considering a cylinder of length x and rearranging the equation to eliminate the -ve sign gives:

$$Q = 2\pi \times k \frac{(T1 - T6)}{\ln(R6/ R1)} \quad (\text{where } \ln = \log_e)$$

rearranging the equation gives:

$$k = \frac{Q \ln(R6/ R1)}{2\pi x (T1 - T6)}$$

The heat flow path in the HT12C consists of a cylinder 3.2 mm long (thickness of disk x) with inside radius R1 = 7 mm (where thermocouple T1 is located) and outer radius R6 = 50 mm (where thermocouple T6 is located).

The object of this exercise is to determine the conductivity of the disk material from measurements of temperature difference and heat flow through the cylindrical disk.

Procedure

(Refer to the Operation section if you need details of the instrumentation and how to operate it.)

Switch on the MAINS switch (21). (If the panel meters do not illuminate check the RCD at the rear of the service unit (35), the switch should be up.)

If using a computer, check that the software indicates IFD OK in the bottom right hand corner of the software window.

Adjust the cooling water flow control valve to give approximately 1.5 litres/min. If using a computer, adjust the valve using the control box on the mimic diagram. If operating the equipment manually using the HT10XC console, set the upper display selector switch to L/min and observe the upper display panel while adjusting the AUXILIARY CONTROL knob.

Set the Heater Voltage to 12 Volts. If using a computer, adjust the voltage using the control box on the mimic diagram. If operating the equipment manually using the HT10XC console, set the upper display selector switch to V (volts) and observe the upper display panel while adjusting the AUXILIARY CONTROL knob.

Allow the HT12C to stabilise. If using a computer, monitor the temperatures on the mimic diagram. If using the console, monitor the temperatures using the lower selector switch/meter (27/26).

When the temperatures are stable, select the  icon if using the computer to take a set of results, or manually record the following if using the console:

T1, T2, T3, T4, T5, T6, V, I, Fw*

(*Fw will not be available with the HT12 unless the optional flow sensor SFT2 is fitted).

Set the heater voltage to 17 volts.

Allow the H12C to stabilise then repeat the above readings.

Set the Heater Voltage to 21 Volts.

Allow the HT12C to stabilise then repeat the above readings.

Set the Heater Voltage to 24 Volts.

Allow the HT12C to stabilise then repeat the above readings.

Results and Calculations

For this exercise the raw data is tabulated under the following headings:

Heater Voltage	V	Volts
Heater Current	I	Amps
Temperature at 7 mm radius (inside)	T1	(°C)
Temperature at 10 mm radius	T2	(°C)
Temperature at 20 mm radius	T3	(°C)
Temperature at 30 mm radius	T4	(°C)
Temperature at 40 mm radius	T5	(°C)
Temperature at 50 mm radius (outside)	T6	(°C)
Cooling water flowrate	Fw	(l/min) If sensor SFT2 is fitted.

You should also estimate and record the experimental errors for these measurements.

For this exercise the following constants are applicable:

Radius at thermocouple T1	R1	= 0.007	(m)
Radius at thermocouple T6	R6	= 0.050	(m)
Thickness of disk (cylinder length)	x	= 0.0032	(m)

For each set of readings the derived results are tabulated under the following headings:

Heat flow (Power to heater)	$Q = VI$	(Watts)
Thermal conductivity of disk material	$k_{\text{Brass}} = \frac{Q \ln(R6/R1)}{2\pi \times (T1 - T6)}$	(W/m°C)

Estimate the cumulative influence of the experimental errors on your calculated values for Q and kBrass and measured values for R1, R6 and x.

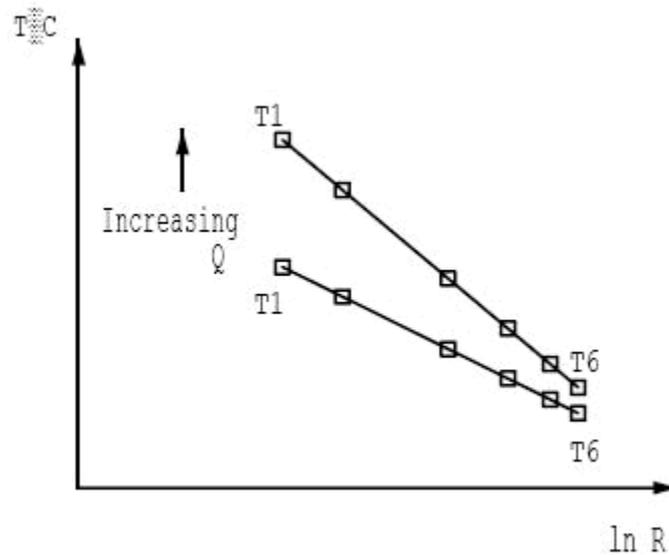
Your results should give the approximate value of 125 W/m°C for the thermal conductivity of Brass sheet.

Compare the values obtained for the Thermal Conductivity kBrass at the different settings of heat flow through the specimen.

Accuracy of the calculated thermal conductivity is increased by using R1/T1 and R6/T6 as temperature difference is greatest at these extreme differences in radius.

Calculate the thermal conductivity of the Brass disk using two different radii and corresponding temperatures. Compare the value obtained with the original value at the same heat flow.

Plot a log/linear graph of radius on the logarithmic axis and temperature on the linear axis then draw the best straight line through the points. The result should be a straight line similar to the diagram below:



Observe that the temperature profile is logarithmic (a straight line is obtained from the points when T is plotted versus $\ln R$) and when results are plotted for different values of radial heat flow Q the gradient of the line increases with increasing heat flow.

Conclusions

You have demonstrated how the Fourier rate equation can be applied to the radial flow of heat through a thick walled cylinder and how the conductivity of the material can be determined from a knowledge of the heat flow radially through the disk, the thickness of the disk and the change in temperature between two different radii in the disk.

Note: Exercise C should be carried out on the completion of this exercise.

Exercise C - Unsteady State Conduction

Objective

To observe unsteady state conduction of heat (qualitative only). As this experiment requires continuous data logging, it is only possible when using computer control of the accessory.

Method

By monitoring the transient changes in temperature through the cylindrical disk when a step change is applied to the heat flow through the disk.

Equipment Required

HT10XC Heat Transfer Service Unit

HT12C Computer Compatible Radial Heat Conduction Accessory

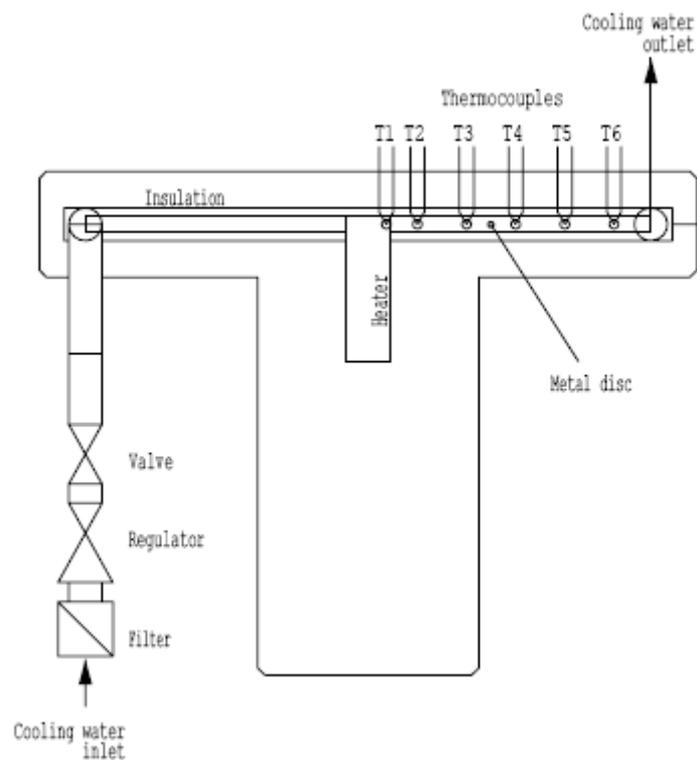
or

HT12 Radial Heat Conduction Accessory

Optional Equipment

SFT2 Flow sensor (if using HT12 instead of HT12C)

Equipment set-up



Before proceeding with the exercise ensure that the equipment has been prepared as follows:

Locate the HT12C Radial Heat Conduction accessory (1) alongside the HT10XC Heat Transfer Service Unit (19) on a suitable bench.

Connect the six thermocouples on the HT12C (18) to the appropriate sockets on the front of the service unit HT10XC (29). Ensure that the labels on the thermocouple leads (T1 - T6) match the labels on the sockets.

On the console, set the VOLTAGE CONTROL potentiometer (22) to minimum (anticlockwise) and the REMOTE/MANUAL selector switch (21) to MANUAL, then connect the heater lead from the HT12C (11) to the socket marked Output 2 at the rear of the service unit (35).

Connect the cold water flow control valve (13) to the socket marked AUXILIARY CONTROL (34) on the HT10XC console.

Connect the cold water flow rate sensor (7) to the socket marked Fw (36) on the HT10XC console.

Set the REMOTE/MANUAL selector switch on the console (21) back to REMOTE.

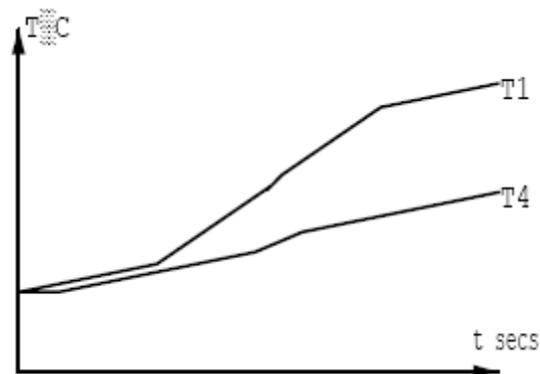
Ensure that a cold water supply is connected to the inlet of the pressure regulating valve on HT12C (15). The water supply should be on.

Ensure that the flexible cooling water outlet tube is directed to a suitable drain.

(If using the HT12 with the optional flow sensor SFT2, instead of the HT12C, connect the sensor to the outlet of the HT12C using the quick release connector. Ensure that the flow arrow on the body of the sensor points towards the drain.)

Ensure that the service unit is connected to an electrical supply.

Theory/Background



This exercise is qualitative only and intended to show the transient/time-dependent behaviour of a system where temperature varies with time and position. This condition, referred to as unsteady-state, exists when the cylindrical disk on the HT12C is first heated and continues until it reaches equilibrium. Similarly the condition exists if a step change is applied such as reducing the heater power or reducing the flow of cooling water.

When heat is applied to centre of the disk the elevated temperature at the centre causes heat to flow towards the cold periphery of the disk. The result is a gradual rise in the temperature of the disk until the appropriate temperature gradient is established throughout the disk (as studied in previous exercises). The changes in temperature cannot occur instantaneously and changes away from the centre will lag the changes at the heated centre despite being smaller in magnitude. Similarly the

smaller changes towards the periphery of the disk will lag the changes mid way through the disk.

Note: Unsteady-state heat transfer can be analysed in much greater detail using the Armfield HT17C.

Procedure

(Refer to the Operation section if you need details of the instrumentation and how to operate it.)

Switch on the MAINS switch (21). (If the panel meters do not illuminate check the RCD at the rear of the service unit (35), the switch should be up.)

Check that the software indicates IFD OK in the bottom right hand corner of the software window.

Adjust the cooling water flow control valve to give approximately 1.5 litres/min using the control box on the mimic diagram.

In the software, select 'Sample' from the top menu bar. Select 'Configure...'

In the Sample Configuration window, check that Sampling Operation is set to Automatic. The Sample Interval should be 30 seconds and the Duration of Sampling should be Continuous.

Select the  icon to start sampling.

Set the Heater Voltage to 21 Volts using the voltage display box on the mimic diagram.

Allow the HT12C to stabilise (monitor the changing temperatures using mimic diagram display).

When the temperatures are stable, wait for 1 minute set the Heater Voltage to 12 Volts.

Allow the HT12C to stabilise and wait a further 1 minute.

If time permits reduce the flow of cooling water dramatically by closing the flow control valve (not the pressure regulating valve) but do not stop the flow of water altogether.

Allow the HT12C to stabilise and wait a further minute.

Select the  icon to end sampling. If time is limited, omit the change of cooling water flow and stop sampling after the previous step.

Results and Calculations

The transient behaviour of the heated disk is best analysed graphically using the recorded graphs of temperature versus time. You should observe the following features on the graphs obtained:

When the heating element is switched on the temperatures throughout the disk gradually rise until the steady-state temperature gradient is achieved.

The rise in temperature at T4 occurs slightly later than the rise at T1 because of the time required for the heat to flow through the disk.

The rise in temperature at T4 is smaller than the rise at T1 because of the temperature gradient through the disk due to conduction.

When the heat input is reduced the heat flow cannot support the original temperature gradient and temperatures through the disk must reduce until an appropriate temperature gradient is achieved.

When the flow of cooling water is reduced the periphery of the disk cannot be maintained at the original low temperature. As all other conditions are unchanged, the gradient through the disk will remain the same resulting in an offset in all of the temperatures (all temperatures across the disk will increase by the same amount). This effect should be clearly shown on the graphs plotted of temperature versus distance.

Conclusions

You have observed how, in a solid, temperature changes with time and position while heat flows from hot boundaries to cold boundaries and temperature gradients are established. This condition of unsteady-state heat transfer exists until a constant temperature gradient has developed and a condition of steady-state is achieved.

Note: Refer to Exercise D for details on additional project work.

Project Work

Designing a model to demonstrate heat transfer by radial conduction

An interesting project for students who have completed the previous training exercises is to build and test a heat transfer model of their own design.

The HT10XC service unit provides the necessary power supplies and instrumentation to operate such a model. Provided that the model is constructed with the following principles it can be connected directly to the HT10XC service unit for evaluation:

The heater must operate from a 24 VDC electrical supply at a maximum current of 9 Amps (216 Watts maximum).

The thermocouples must be type K and terminated with a miniature thermocouple plug.

Typical projects might include:

- Evaluation of radial heat flow through disks of different materials.
- Heat flow from the periphery to centre of a disk (heat applied to the circumference and cooling at the centre).
- Heat flow through a quadrant of disk material (a full circle is not required due to the symmetrical pattern of the heat flow).

Where appropriate, any of the Exercises A, B or C might be applied to the project model constructed by the student.

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