PROCESS INSTRUMENTATION I

Learning Guide: First Semester 2018

Module Code: EIPIN1B

VUT
Vaal University of Technology

INDEX

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PART II Learning Units

Unit 1

Unit 2

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Unit 4

1. WORD OF WELCOME

The Department of Process Control and Computer Systems, welcomes you as a student to the Faculty of Engineering at the Vaal University of Technology. The department strives towards integration of existing knowledge with new knowledge and to afford the student the ability to think logically, gain knowledge of Electrical Engineering, and specifically Process Instrumentation, in order to make a positive contribution to the field of Industrial Instrumentation and Electrical Engineering.

2. CONTACT PERSONS

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3. RATIONALE FOR THE MODULE

On completion of this module you should be knowledgeable in the operation of pressure, flow, level and temperature measuring instruments and competent in the implementation, calibration and maintenance of industrial instruments in an industrial control environment. This module relates closely to all the other modules in the Electrical Engineering Programme since it ought to improve your ability to understand the learning content and formulate your assignments and examination answers.

4. PREREQUISITES

No previous exposure to instrumentation technology is assumed. Students are however expected to be competent computer and internet users for the purpose of research and to obtain additional learning material. Students are also expected to have received excellent results in Mathematics and Science for grade 12 and therefore in possession of solid basic mathematical skills.

5. LEARNING MATERIAL

This learning guide as well as the course material and previous evaluations, will be made available to students at the beginning of the semester.

6. ASSESSMENT

Module assessment will take place on a continuous basis, and for this purpose the module is divided into four units.

- Unit 1: Chapters 1 to 3 (weight=35%)
- Unit 2: Chapters 4 to 6 (weight=35%)
- Unit 3: Project (weight=10%)
- Unit 4: Laboratory assignments (weight=20%)

i) **Module assessment:** To successfully complete each unit, **students must receive a unit mark of at least 50%.** To successfully complete the module, **students must complete all the units.** A student that successfully completes the module will receive a module mark according to the following summative assessment schedule:

$$\text{Module\%} = 0.35\times\text{Unit1\%} + 0.35\times\text{unit2\%} + 0.1\times\text{unit3\%} + 0.2\times\text{unit4\%}.$$

The continuous assessment programme does not allow for supplementary or rewritten examinations. Students that fail to complete this module, must resume their studies by completing **all units** again during a subsequent semester.

ii) **Unit 1 assessment (1½ hour session):** Assessment of unit 1 is scheduled for Friday 9 March 2018 at 14h00. Students that fail to receive 50% for unit 1, will be offered a second and **final** opportunity to complete unit 1 on Friday 20 April 2018 at 14h00. Students who successfully complete the final assessment, will however receive a maximum mark of 50% for unit 1. Students who were unable to attend the first assessment session, will receive the full mark obtained for the final assessment of unit 1. The assessment venues (main campus) that may be available are G302, G305, G306, T104 and T203, while assessment venues will be arranged for the satellite campuses. A student that fails to receive 50% for the final attempt to complete unit 1, fails the module.

iii) **Unit 2 assessment (1½ hour session):** Assessment of unit 2 will take place on Friday 13 April 2018 at 14h00. Students that fail to obtain 50% for unit 2, will be offered a second and **final** opportunity to complete unit 2 on Friday 11 May 2018 at 14h00. Students who successfully complete the final assessment, will however receive a maximum mark of 50% for unit 2. Students who were unable to attend the first assessment session, will receive the full mark obtained for the final assessment of unit 2. The assessment venues (main campus) that may be available are G302, G305, G306, T104 and T203 while assessment venues will be arranged for the satellite campuses. A student that fails to receive 50% for the final attempt to complete unit 2, fails the module.

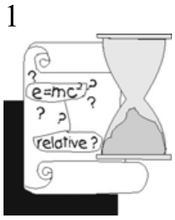
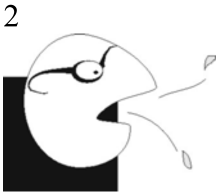
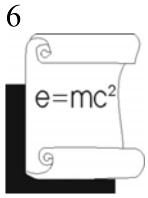
iv) **Unit 3 assessment:** For the purpose of assessing unit 3 (project), each student will demonstrate the operation of a thermometer, constructed according to the guidelines given in the learner guide for unit 3. Unit 3 will be assessed in the lecture room, on the date and time scheduled by the lecturer. A clear photograph (as well as a copy of the photograph) showing the project with the student's student card (or other clear identification), must also be available when the project is assessed. Students that fail to receive 50% for unit 3, will be presented with a second and **final** opportunity to complete unit 3, on the date and time scheduled by the lecturer. Students that successfully complete unit 3 with the final assessment, will however receive a maximum mark of 50% for unit 3. A student that fails to receive 50% for the final attempt to complete unit 3, fails the module.

v) **Unit 4 assessment:** Unit 4 will be assessed on a continuous basis during the semester. Students will receive the assessment dates and times for their laboratory assignments, at the beginning of the semester after lecturing has started. The assessment venue is room J003 on the main campus. Assessment venues and dates will be scheduled for satellite campuses. A student that is unsuccessful in obtaining 50% for unit 4, will **not** be presented with a second opportunity to complete unit 4 and fails the module.

vi) **Module portfolio:** The module portfolio is a collection of all the assessment material produced by a student for unit 3 and unit 4 during the semester, neatly put together in a folder. Any relevant medical certificates, death certificates or other official documents supporting the reasons for not attending an assessment session, should be included in the portfolio. Students should not include their physical project (unit 3) in the portfolio but rather a copy of the project photograph that formed part of their project demonstration.

Each student must purchase a plastic folder of **exactly** the type shown here to the right. The choice of colour is left to each student's personal taste, except that the folder must be transparent so that the header page will be visible inside the folder. The header page must be labelled with the module name (Process Instrumentation I EIPIN1), year, semester and group (period A to H), as well as the name of the student and student number. Students should hand in the folder with their first laboratory assignment. Students will have the opportunity during the first practical period after the practical programme has ended, to prepare their module portfolio and verify that all relevant material is included before it is collected for assessment, moderation and calculation of the final mark for unit 4.

7. ICONS USED IN THIS STUDY GUIDE

1 	2 	3 	4 	5 	6 
Estimated study time	Opening remarks and introduction	Outcomes	Study the following passage thoroughly	Practical work	Exam questions and assessment

8. ACTION VERBS

In preparation for your studies in this module the action verbs used in the assessment of your work in this module are given to you in advance. Make sure that you understand the meaning of each and that you deliver your work accordingly.

- **Define** To supply the accurate meaning of a concept. [*Example: Define pressure.*]
- **Name/mention/list/state/write down/give** Briefly provide required information without giving details. Neither a discussion nor an explanation is necessary. [*Example: Give the temperature of the oxygen point on the international temperature scale* or *State two direct methods of measuring the level in a container.*]
- **Outline** Emphasise the major features or general principles of a topic. Slightly more detail than in the case of naming, listing or stating of information is required. [*Example: Outline the essential features of the Celsius temperature scale.*]
- **Comment** Briefly stating your own opinion on a subject. [*Example: Comment on the relevance of instrumentation in process control.*]
- **Indicate** Point out, make known, state briefly. [*Example: Indicate the advantage of using an annubar flow meter over a pitot tube flow meter.*]
- **Identify** Give the essential characteristics or aspects of a phenomenon. [*Example: Identify the forms of energy, involved in a liquid in motion.*]
- **Demonstrate** Include and discuss examples. You have to prove that you understand how a process works or how a concept is applied in real-life situations. [*Example: Demonstrate how Archimedes's principle is applied when measuring level with the torque tube level indicator.*]
- **Describe** Say exactly what something is like, give an account of the characteristics or nature of something, explain how something works. No opinion or argument is needed. [*Example: Describe the operation of a pneumatic differential pressure transmitter.*]
- **Discuss** Comment on something in your own words. Often requires debating two viewpoints or two different possibilities. [*Example: Discuss the relative advantages and disadvantages of using a venturi tube or an orifice plate, to measure flow rate.*]
- **Example** A practical illustration of a concept is required. [*Example: Give an example of a linear movement valve.*]
- **Explain/clarify** Clarify or give reasons for something, usually in your own words. You must prove that you understand the contents. It may be useful to use examples or illustrations. [*Example: Briefly explain the term hysteresis.*]
- **Illustrate** Draw a diagram or sketch the representation of a phenomenon or idea. [*Example: Illustrate with a sketch how a u-tube manometer can be used to measure differential pressure.*]
- **Motivate** You should give an explanation of the reasons for your statements or views. You should try to convince the reader of your view. [*Example: Motivate the control strategy that you will use for a lecture room temperature controller.*]

- **Summarise** Give a structured overview of the key (most important) aspects of a topic. This must always be done in your own words. [*Example: Give a summary of the measurement errors that may occur while using an instrument.*]
- **Analyse** Identify parts or elements of a concept. [*Example: Identify the elements that constitute a typical instrument.*]
- **Distinguish/compare/contrast** Point out the similarities and the differences between objectives, ideas or points of view. When you compare two or more objectives, you should do so systematically – completing one aspect at a time. It is always better to do this in your own words. [*Example: Distinguish between direct level measurement and indirect level measurement.*]
- **Debate** Logically formulate an argument by discussing opposing viewpoints, such as similarities and dissimilarities; pros and cons; advantages and disadvantages on a given topic. Follow a question attitude and hold a formal argument. [*Example: Debate the desirability of using resistance thermometers, in favour of thermocouple thermometers.*]
- **Essay** An extensive description of a concept is required. [*Example: Write an essay on the fundamental units and standards used in instrumentation.*]
- **Criticise** This means that you should indicate whether you agree or disagree with a certain statement or view point. You should describe what you agree/disagree with and give reasons for your view. [*Example: Write critical comments about the use of pneumatic controllers in a growing digital instrumentation environment.*]
- **Evaluate** This means that you should analyse a theory, article, prescribed book, etc. to determine its worth or value. You should constantly indicate whether you agree or disagree with statements made, and motivate your point of view. [*Example: Evaluate the four wire method as compensation method for ambient temperature variations in resistance thermometers.*]
- **Draw a mind map/block diagram/figure** Outline the main concepts pertaining to the study material by drawing a diagram and completing the concepts in telegram style. Also indicate the relationships between the different concepts. [*Example: Draw a block diagram of a self-regulated control system (feedback system).*]
- **Calculate / determine / solve / convert** Use the given numerical data to arrive at the value of an unknown variable. [*Example: Calculate the pressure in pascal, that corresponds to a pressure of 1000 mm mercury* or *Convert a pressure of 1000 mm mercury to a pressure expressed in pascal.*]
- **Derive / Show** Starting from a given premise, give the necessary steps to arrive at the result in question. [*Example: Derive the flow equation* $q = k\sqrt{h}$*, starting with Bernoulli's law and the principle of flow continuity.*]
- **Sketch / Draw / Make a sketch** Draw a diagram, normally with accompanying labels, of a device to identify its components/elements/parts/mechanisms and/or illustrate its operation/implementation. [*Example: Make a labelled sketch of a pneumatic pilot relay.*]

9. MODULE PLAN

Learning unit 1	Introduction to Industrial Instrumentation Pressure Measurement Flow Measurement
Learning unit 2	Level Measurement Temperature Measurement Process Control
Learning unit 3	Thermometer project
Learning unit 4	Laboratory assignments Module portfolio

10. TIME SCHEDULE / LEARNER WORK PROGRAM

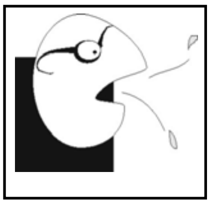
You must make sure of all the dates of classes, tutorials, practical classes, dates for the submission of assignments etc. as spelt out in the work program. The following provisional time schedule is provided as a tentative guideline for the work programme, and the exact agenda will change according to the information and time tables that will be available during the semester.

Week	**Activity**
1	Learning unit 1
2	Learning unit 1
3	Learning unit 1, Practical 1 assessment
4	Learning unit 1, Practical 2 assessment
5	Learning unit 2, Practical 3 assessment, Unit 1 first assessment
6	Learning unit 2, Practical 4 assessment
7	Learning unit 2, Practical 5 assessment
8	Learning unit 2, Practical 6 assessment, Unit 1 final assessment
9	Practical 7 assessment, Unit 2 first assessment
10	Unit 3 first assessment
11	Unit 3 final assessment
12	Unit 2 final assessment

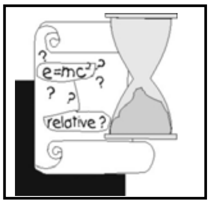
11. MODULE OUTCOME

1. **Understand and explain measurement and control terminology as is applicable to control instrumentation.**
2. **Understand and explain instrument equipment used to measure specific variables.**
3. **Describe the methods and equipment used to control industrial process variables.**

1. LEARNING GUIDE - UNIT 1: INTRODUCTION TO INDUSTRIAL INSTRUMENTATION



The overall objective of this learning unit is to introduce students to the fundamental definitions of measurement and control, and to provide students with an overview of the procedures and practices in process instrumentation.



You should spend approximately 10 hours on this learning unit.

LEARNING UNIT OUTCOME

After completion of this learning unit, students should be able to:

- **Define measurement and measurement units and standards.**
- **Define, analyse and discuss the functional elements of instruments.**
- **Define range and span and the static characteristics of an instrument.**
- **Identify and define different instrument errors and explain their effect on instrument behaviour.**
- **Analyze instrument drawings and identify standard instrument symbols.**

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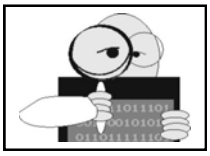
1.1 Measurement standards

1.1.1 Learning Section Outcome

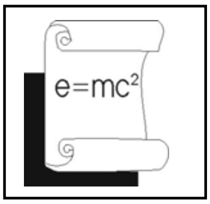
At the conclusion of this section, students will be able to describe and define the purpose of measurement and the units and scales against which measurements are made.

1.1.2 Learning Schedule



The material for this section is available in the notes, sections 1.1 and 1.2, Chapter 1.

1.1.3 Assessment



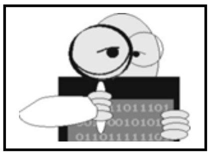
Students will be required to define measurement and state the base units of the SI system. Students should know and understand international standards, primary standards, secondary standards and working standards and be able to define and explain the role of each standard in a measurement environment.

1.2 Functional elements of instruments

1.2.1 Learning Section Outcome

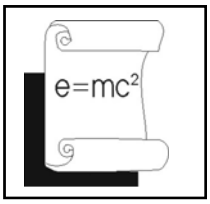
Students studying and completing this section, will be able to define and describe in detail, the functions of instruments and the typical elements found in instruments.

1.2.2 Learning Schedule



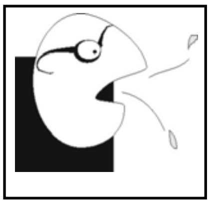
The study material for this section is available in the notes, section 1.3, Chapter 1.

1.2.3 Assessment



Students must be able to define and discuss the three functions (indicating, recording and controlling) that instruments perform and identify and define the elements (primary, transmission, secondary, manipulation and presentation) in a typical instrument and using a mercury filled thermometer as an example, explain and discuss each element in detail.

1.3 Static characteristics of instruments



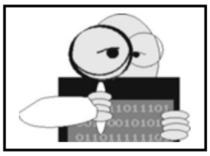
The purpose of this section is to gain knowledge and insight regarding the static characteristics of instruments. Of special interest is the procedure to determine the static calibration of an instrument as well as the concept of an *ideal* static calibration curve.

1.3.1 Learning Section Outcome

After completing this section, students will be able to describe the following important characteristics, associated with the static behaviour of instruments:

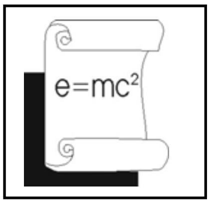
- Instrument range and span.
- Static calibration curve.
- Error of measurement and accuracy.
- Precision, repeatability and reproducibility.
- Resolution and sensitivity.

1.3.2 Learning Schedule



The study material for this section is available in the notes, sections 1.4 and 1.5, Chapter 1.

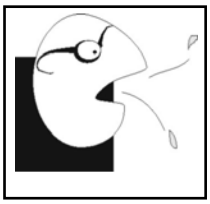
1.3.3 Assessment



Students will be required to develop a thorough understanding of all the static characteristics of instruments, so that they will be able to accurately and precisely, reproduce the definitions of the following concepts, related to the static behaviour of instruments:

- Instrument range and span.
- Static calibration curve.
- Error of measurement accuracy.
- Precision, repeatability and reproducibility.
- Resolution and sensitivity.

1.4 Instrument errors

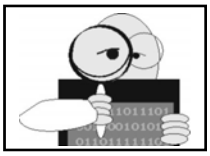


The objective of this section is to introduce students to the three main classes of errors that may materialize during a measurement session; gross errors, systematic errors and random errors. Typical instrument errors; non-linearity, drift, hysteresis and dead band errors, will then be discussed.

1.4.1 Learning Section Outcome

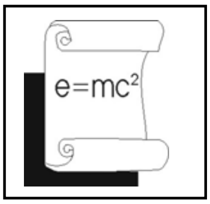
At the conclusion of this section, students will be able to define and explain the significance of gross errors, systematic errors and random errors and define the following instrument errors: non-linearity error, drift, hysteresis and dead band error.

1.4.2 Learning Schedule



The study material for this section is available in the notes, section 1.6, Chapter 1.

1.4.3 Assessment



Students must be able to:

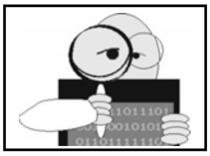
- Define and explain the significance of gross errors, systematic errors and random errors.
- Define the meaning of non-linearity, drift, hysteresis and dead band errors.

1.5 Industrial instrumentation schematics

1.5.1 Learning Section Outcome

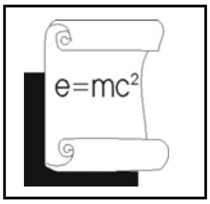
This section concludes the introduction to industrial instrumentation. After studying this section, students will be able to analyse and interpret typical industrial instrumentation schematic diagrams.

1.5.2 Learning Schedule



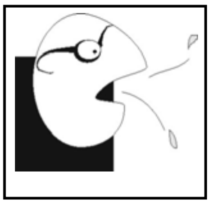
The study material for this section is available in the notes, section 1.7, Chapter 1.

1.5.3 Assessment

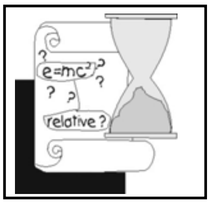


Students must be able to identify and reproduce all the important instrument symbols and instrument identification lettering abbreviations as well as the line and supply conventions used for signals and interconnections between instrument blocks.

2. LEARNING GUIDE – UNIT 1: PRESSURE MEASUREMENT



The purpose of this learning unit is to introduce students to the definitions and units of pressure related quantities and to discuss typical methods to measure pressure.



You should spend approximately 15 hours on this learning unit.

LEARNING UNIT OUTCOME

After completion of this learning unit, students should be able to:

- Define pressure, density, relative density, absolute zero of pressure, absolute pressure, atmospheric pressure, gauge, vacuum and differential pressure.
- Derive the expression for pressure in a liquid: $P = \rho hg$, and use this equation to solve elementary pressure problems.
- Understand, describe the operation and illustrate the construction of the following pressure measuring instruments: manometers, Bourdon gauges, bellows pressure sensors, diaphragm and capsule sensors, force balance hydrostatic testers and differential pressure transmitters.
- Explain the operation and discuss the construction of strain gauges and describe with sketches and operational equation, its implementation in a Wheatstone quarter bridge arrangement.

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2.1 Introduction and Definitions

2.1.1 Learning Section Outcome

After completing this section, students will be able to:

- Understand and define the concepts of pressure, density, relative density, absolute zero of pressure, absolute pressure, atmospheric pressure, gauge pressure, vacuum pressure and differential pressure.
- Recall that ρ_{water} = 1000kg/m^3, $\rho_{mercury}$ = 13600 kg/m^3, $\rho_{transformer\ oil}$ = 864kg/m^3, ρ_{air}=1.2kg/m^3 and that $P_{atmosphere}$ = 101.325 kPa. or 760 mm. mercury.
- Convert between density and relative density, using $\rho = 1000\delta$.

2.1.2 Learning Schedule

The study material for this section is available in the notes, section 2.1, Chapter 2.

2.1.3 Assessment

Successful students will be required to demonstrate that they are able to accurately define pressure, density, relative density, absolute zero of pressure, absolute pressure, atmospheric pressure, gauge pressure, vacuum pressure and differential pressure and that they can give the correct SI units, where applicable.

2.2 Pressure in a liquid

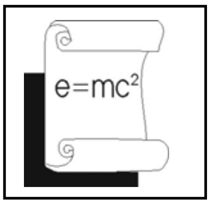
2.2.1 Learning Section Outcome

After completing this section, students will be able to derive the fundamental formula for the pressure in a liquid, $P=\rho hg$ and perform pressure calculations, where this expression is applied.

2.2.2 Learning Schedule

The study material for this section is available in the notes, section 2.2, Chapter 2.

2.2.3 Assessment



Students will demonstrate that they are able to give a precise derivation of the formula P=ρhg and that they are skilful in its application. Students will be expected to perform simple pressure calculations and perform conversions from a pressure expressed in pascal, to mm. mercury (mm Hg) or mm. water (mm H_2O) and vice versa. (For example: Convert a pressure of 33 cm. water into a pressure expressed in pascal and also in mm. mercury.)

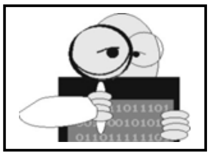
2.3 Pressure measurement with manometers

2.3.1 Learning Section Outcome

After completing this section, students will be able to:

- Describe and illustrate the use of a u-tube manometer to measure gauge pressure, differential pressure and absolute pressure.
- Sketch and derive the operational equation of the well type manometer and the inclined limb manometer.
- List the typical liquids used in manometers, and describe the properties of each liquid.

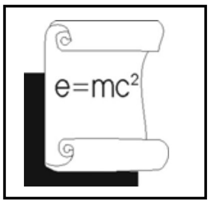
2.3.2 Learning Schedule



The study material for this section is available in the notes, section 2.3, Chapter 2.

Students must complete practical assignment 1 (u-tube and well type manometer), that is relevant to this learning section, but forms part of unit 4.

2.3.3 Assessment



Students will demonstrate their competence with the knowledge accumulated, by means of the following assessment schedule:

- Sketch, describe and give the relevant equations with respect to using a u-tube manometer to measure gauge pressure, differential pressure and absolute pressure. Perform simple pressure calculations where for instance the manometer is filled with liquids of different densities or when the one tube is closed. (For example: (a) The two legs of a u-tube is open to atmosphere and filled with mercury up to the zero line. Water is added to the right hand leg, up to 1 meter. Calculate the mercury level difference. (b) The two legs of a u-tube manometer are open to atmospheric pressure. One leg is sealed and 150 kPa is applied to the open tube. Calculate the manometer reading.)

- Describe the operation and derive the equations governing the operation of a well type manometer and an inclined limb manometer. Students will demonstrate that they can apply these formulas to real world problems.
- Discuss manometer liquids with respect to relative density, advantages, disadvantages and applications.

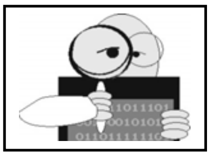
2.4 Measuring pressure with elastic structures

2.4.1 Learning Section Outcome

Students will acquire an understanding of the principle of operation of the following pressure sensitive devices, of which the operation is based on elastic deformation:

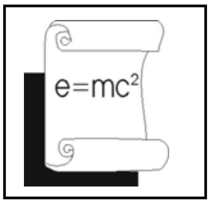
- C type Bourdon tube gauge.
- Bellows pressure sensors.
- Diaphragm pressure sensors.

2.4.2 Learning Schedule



The study material for this section is available in the notes, section 2.4, Chapter 2.

2.4.3 Assessment



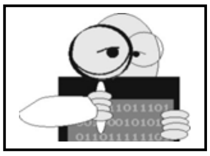
Students will be required to explain the operation and make detailed labelled sketches of the Bourdon gauge instrument, the bellows pressure sensor and the diaphragm pressure sensor. As with the u tube manometer, students will be required to make labelled sketches of a bellows element in the role of measuring gauge pressure, differential pressure and absolute pressure.

2.5 Measuring pressure with the force-balance gauge

2.5.1 Learning Section Outcome

Students will acquire an understanding of the operation of the force-balance gauge, and it's specific application to calibrate other pressure measuring devices.

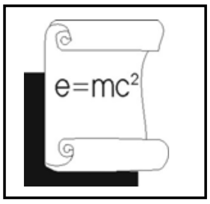
2.5.2 Learning Schedule



The study material for this section is available in the notes, section 2.5, Chapter 2.

Students must complete practical assignment 2 (hydrostatic test balance), that is relevant to this learning section, but forms part of unit 4.

2.5.3 Assessment



Students will be required to sketch and explain the operation of the force-balance gauge, and use the formula, $P=(m_{platform}+m_{masspieces})g/A$, to perform simple mass piece calculations, for different calibration situations.

2.6 Measuring pressure with the differential pressure transmitter

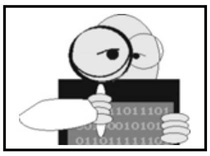
2.6.1 Learning Section Outcome

Students will understand the principle of operation of the pneumatic differential pressure transmitter as well as the describing equation:

$$P_0 = m(P_1 - P_2) + 20 \text{ kilopascal.}$$

Students will also be able to explain the operation of the pilot relay, that is used in instruments such as the differential pressure transmitter.

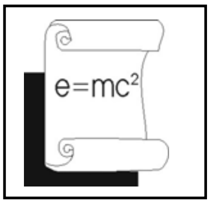
2.6.2 Learning Schedule



The study material for this section is available in the notes, section 2.6, Chapter 2.

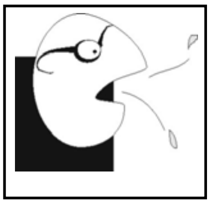
Students must complete practical assignment 3 (Pneumatic D/P transmitter) and practical assignment 4 (Electronic D/P transmitter), that are relevant to this learning section, but forms part of unit 4.

2.6.3 Assessment



Students will be required to provide a labelled sketch of a pneumatic differential pressure transmitter and explain its operation in detail. Students must be able to demonstrate their skill with the describing equation, by performing simple calibration calculations. (For example: a DP transmitter is correctly calibrated for a process variable that varies from 0 kPa to 170 kPa. Determine the output of the DP transmitter when the process pressure reaches 90 kPa.). A pneumatic pilot relay enhances the operation of the flapper and nozzle and students will be expected to make a labelled sketch of a pilot relay and describe its operation.

2.7 Strain gauges

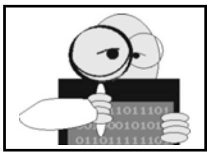


As so many instruments need to convert a pressure variable into an electrical signal, the strain gauge will be presented as one device that may be used to convert a pressure or force related variable into a standard 4 to 20 mA or 1 to 5 V electrical signal.

2.7.1 Learning Section Outcome

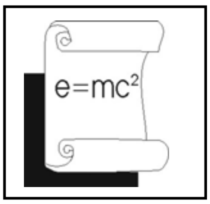
After completing this section, students will understand the operation of a strain gauge, and describe its construction and the connection of a strain gauge in a quarter bridge Wheatstone configuration, as one example of the possible bridge structures.

2.7.2 Learning Schedule



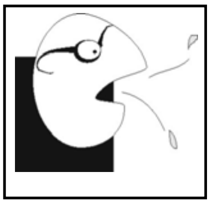
The study material for this section is available in the notes, section 2.7, Chapter 2.

2.7.3 Assessment

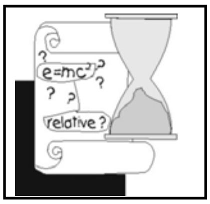


Students should be able to discuss the change in the resistance of a metal wire with reference to the equation $R = \rho\ell/a$, produce a labelled sketch of the typical construction of a foil type strain gauge and give the definition of the gauge factor. Students will also be required to draw a Wheatstone bridge, explain the operation of a quarter bridge structure and perform simple calculations based on the equation for the bridge output voltage in terms of the gauge factor GF, and the strain ε.

3. LEARNING GUIDE – UNIT 1: FLOW MEASUREMENT



The purpose of this learning unit, is to familiarize students with concepts related to volumetric flow and flowrate, and to introduce students to basic flow measurement techniques.



You should spend approximately 15 hours on this learning unit.

LEARNING UNIT OUTCOME

After completion of this learning unit, students should be able to:

- Define:
  volumetric flow and flow rate, viscosity and Poiseuille's law, streamlined flow, turbulent flow and the Reynolds number, pressure energy, kinetic energy and potential energy in a flow stream, Bernoulli's law, static pressure, dynamic pressure and stagnation pressure.
- Sketch, describe and give the operational equation of the Pitot tube.
- Derive the flow equation $q = k\sqrt{h}$, starting with Bernoulli's law and the principle of conservation of mass.
- Sketch and discuss the operation of the venturi tube and the orifice plate.
- Sketch, discus the operation and give the relevant operational equation for the target flow rate meter, rotameter, vortex flow rate meter, magnetic flow rate meter, Doppler flow rate meter, transmissivity flow rate meter and the Coriolis mass flow rate meter as well as the turbine volumetric flow meter and the reciprocating piston positive displacement volumetric flow meter.

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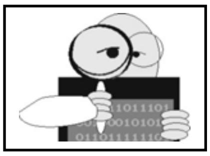
3.1 Introduction

3.1.1 Learning Section Outcome

After completing the prelude to this unit, students will be able to:

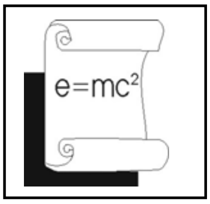
- Define volumetric flow and flowrate.
- Define viscosity of liquids and gasses and Poiseuille's law.
- Define streamlined flow, turbulent flow and the Reynolds number.
- Identify the energy components of a liquid in motion and define Bernoulli's law.
- Define static pressure, dynamic pressure and stagnation pressure and describe and illustrate the operation of the Pitot tube.

3.1.2 Learning Schedule



The study material for this section is available in the notes, sections 3.1 to 3.7, Chapter 3.

3.1.3 Assessment



Successful students will be required to demonstrate that they have reached the predetermined outcome for this learning section by revealing their ability to:

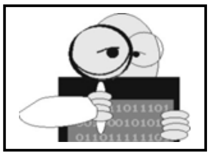
- Define volumetric flow and flow rate and give the corresponding SI units.
- Define viscosity and give the SI unit and the expression for viscosity.
- Define streamlined flow, turbulent flow, give the expression for the Reynolds number and explain the relation between the Reynolds number and the mode of flow. Sketch and explain the purpose of flow straighteners.
- Perform simple flow rate calculations with Poisuille's equation.
- Define, with corresponding equations and SI units, pressure energy, kinetic energy and potential energy. Students should in particular understand that pressure energy = static pressure P, kinetic energy = $\frac{1}{2}\rho v^2$ and potential energy = ρgh, if we consider a unit volume of a liquid.
- State Bernoulli's law.
- Identify, from Bernoulli's equation, static pressure, dynamic pressure potential pressure and stagnation pressure.
- Sketch, describe the operation and give the flow equation for the Pitot tube.

3.2 Derivation of the flow equation

3.2.1 Learning Section Outcome

After completing this section, students will be able to understand how Bernoulli's theorem is applied to obtain the fundamental flow equation, $q = k\sqrt{h}$.

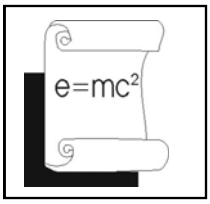
3.2.2 Learning Schedule

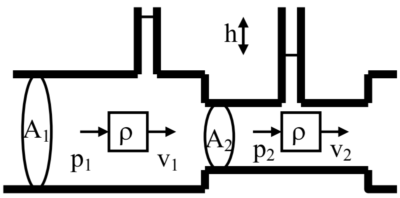


The study material for this section is available in the notes, section 3.8, Chapter 3.

Students must complete practical assignment 5 (practical confirmation of the relationship $q = k\sqrt{h}$), that is relevant to this learning section, but forms part of unit 4.

3.2.3 Assessment





Students will be required to sketch a stream, in a horizontal pipe with a restriction and to define the flow areas A_1, A_2, as well as the liquid level difference h in the measuring tubes. Students must clearly show a unit volume of the liquid (with mass ρ) entering the restriction, under pressure p_1 and moving with velocity v_1 and then the same unit volume, when it reaches the restriction with higher velocity v_2 and under the influence of a smaller pressure p_2.

- Students must now demonstrate that they can apply Bernoulli's law to the unit volume and produce the equation $\frac{1}{2}\rho v_1^2+p_1=\frac{1}{2}\rho v_2^2+p_2$.
- Students will be required to show that they understand the principle of flow continuity in order to calculate the velocity v_1 from $A_1v_1=A_2v_2$.
- Students will now use the relation $v_1=(A_2/A_1)v_2$ to eliminate v_1 from Bernoulli's equation and successfully perform the necessary algebraic manipulations to solve for v_2 and obtain the relation: $v_2 = \sqrt{[2(p_1-p_2)/\rho(1-(A_1/A_1)^2)]}$.
- Students must now use the formula for the flow rate in the restriction, $q = A_2v_2$, to finally write down the flow rate, $q = A_2\sqrt{[2(p_1-p_2)/\rho(1-(A_1/A_1)^2)]}$.

- To conclude their derivation, students will refine and simplify the flow equation, firstly showing that one possible way to measure the pressure difference p_1-p_2, is to simply allow the same liquid as in the flow stream, to rise up in the two tubes mounted across the restriction, so that $p_1-p_2 = \rho hg$ and using this relation, that the flow equation simplifies to $q = A_2\sqrt{[2gh/(1-(A_1/A_1)^2)]}$. Secondly, students will show that introducing a calibration constant $k = A_2\sqrt{[2g/(1-(A_1/A_1)^2)]}$, that from this, the final flow equation $q = k\sqrt{h}$ will follow.

Given the critical importance of the flow equation, students should focus on the exact derivation of the relationship $q = k\sqrt{h}$, as outlined above, when preparing for the assessment of this outcome. In order to demonstrate that students understand the meaning of this equation and especially the implications of the square root relationship, students will be required to perform simple flow calculations based on this equation. Students will also be required to thoroughly understand the expression for the flow velocity in a restricted flow area, $v_2 = \sqrt{[2(p_1-p_2)/\rho(1-(A_1/A_1)^2)]}$, because it explains the intimate relationship between the restricted flow velocity, the pressure difference across the restriction and the restricted and unrestricted flow areas and also because of its direct relevance to the operation of flow meters such as venturi tubes, target meters and rotameters.

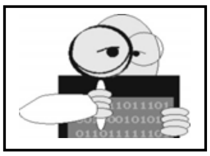
3.3 Differential pressure method of measuring flow

This widely used flowmetering method of placing a flow restriction in the fluid carrying pipe, will be discussed with particular reference to the venturi tube and the orifice plate.

3.3.1 Learning Section Outcome

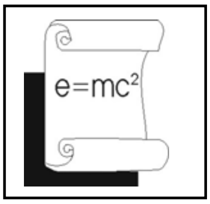
After completion of this section, students will be able to discuss the essential characteristics of a venturi tube flow meter and an orifice plate flow meter.

3.3.2 Learning Schedule



The study material for this section is available in the notes, sections 3.9 and 3.10, Chapter 3.

3.3.3 Assessment



With respect to venturi tubes, students will be required to:

- Make a labelled sketch of a venturi tube, and discuss its operation.
- Give the advantages and disadvantages of a venturi tube.
- Sketch an experimental setup to display the pressure profile across the venturi tube.

With respect to orifice plates, students will be required to:

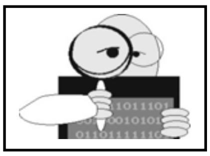
- Sketch the positioning of an orifice plate between two pipe flanges
- Explain the purpose of providing drain and vent holes in orifice plates.
- Sketch and explain under what circumstances, concentric, eccentric and segmental orifice plates are used.
- Discuss the advantages and disadvantages of orifice plates.
- Explain the meaning of the vena contracta position in a flow stream.
- Sketch and discuss the positioning of corner taps, flange taps, radius taps, vena contracta taps and pipe taps, to monitor the pressure difference across an orifice plate.

3.4 Other flowmeters

3.4.1 Learning Section Outcome

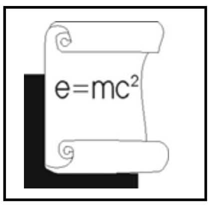
After completing this section, students will be familiar with the operation of the following flow rate meters; target meter, rotameter, vortex flow meter, magnetic flow meter, Doppler flow meter, transmissivity flow meter and the Coriolis flow meter as well as the volumetric turbine flowmeter and reciprocating piston positive displacement flow meter.

3.4.2 Learning Schedule



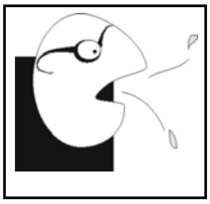
The study material for this section is available in the notes, sections 3.11 to 3.19, Chapter 3.

3.4.3 Assessment

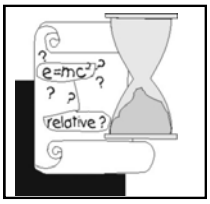


Students will be required to sketch, explain the operation and give operational equations (but not the derivation) where applicable, of the following meters: target meter, rotameter, vortex flow meter, magnetic flow meter, Doppler flow meter, transmissivity flow meter, Coriolis flow meter, turbine volumetric flow meter and reciprocating piston positive displacement volumetric flow meter.

4. LEARNING GUIDE – UNIT 2: LEVEL MEASUREMENT



This learning unit aims to introduce students to the methods and techniques used to measure the fluid level in a container. Most level measurement techniques can be categorized into one of two groups – direct and indirect methods. Direct methods involve measuring the height of fluid directly as for example with a sight glass or float indicator, while indirect methods measure another variable that is correlated to the liquid level.



You should spend approximately 10 hours on this learning unit.

LEARNING UNIT OUTCOME

After completion of this learning unit, students should be able to:

- Sketch and describe the operation of the sight glass and float indicators
- Sketch and describe the differential pressure methods of measuring the level in containers and perform level calculations for open and closed containers

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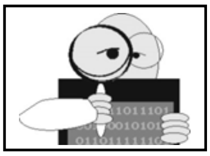
Students must complete practical assignment 6 (measuring the level in a container using various types of equipment), that is relevant to this learning unit, but forms part of unit 4.

4.1 Direct Methods

4.1.1 Learning Section Outcome

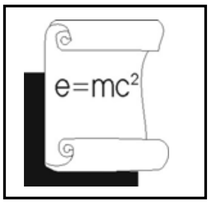
After completing this section, students will be able to describe the operation of the sight glass and float indicators. Although the torque tube indicator is strictly speaking not a float mechanism, students will nevertheless be introduced to the operation of the flexure tube displacer in this section, as manufacturers normally group their floats and displacers together.

4.1.2 Learning Schedule



The study material for this section is available in the notes, sections 4.2 and 4.3, Chapter 4.

4.1.3 Assessment



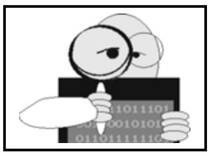
Students will be required to sketch and discuss the operation of the sight glass, float type and displacer level indicators.

4.2 Indirect Methods

4.2.1 Learning Section Outcome

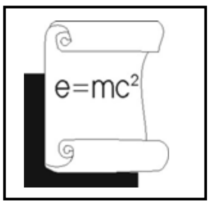
After completing this section, students will be able to describe the measurement of level in open or closed containers by measuring the difference in pressure between the bottom and top of the container by means of differential pressure transmitters, manometers or bubbler systems.

4.2.2 Learning Schedule



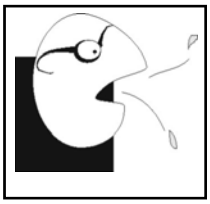
The study material for this section is available in the notes, sections 4.4 and 4.5, Chapter 4.

4.2.3 Assessment

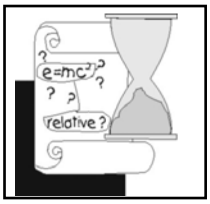


Students will be required to sketch and discuss level measurement in an open and closed container by means of a manometer, differential pressure transmitter or using a gas bubbler. Students will also be required to perform simple calculations regarding differential pressure level measurement.

5. LEARNING GUIDE – UNIT 2: TEMPERATURE MEASUREMENT



The purpose of this learning unit is to introduce students to fundamental concepts related to temperature and to discuss methods to measure temperature.



You should spend approximately 15 hours on this learning unit.

LEARNING UNIT OUTCOME

After completion of this learning unit, students should be able to:

- Define temperature, the bottom and top fixed points and the fixed temperature values on the international temperature scale.
- Convert temperature values between degrees Celsius, degrees Fahrenheit, Kelvin and Rankine.
- Sketch and describe the operation of the ‘filled’ thermometers; mercury in steel, gas filled and vapour pressure as well as the ‘expansion’ thermometers; liquid in glass and bi-metal.
- Sketch and describe the operation of resistance, thermocouple and thermistor thermometer.

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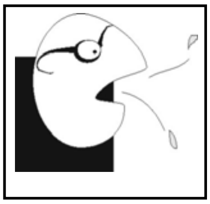
5.1 Introduction

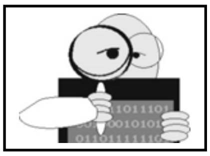


This section aims to introduce students to the fascinating history of temperature measurement, the development of the Fahrenheit and Celsius temperature scales, the definition of temperature, the bottom and top fixed points that are used, as well as the international temperature scale.

5.1.1 Learning Section Outcome

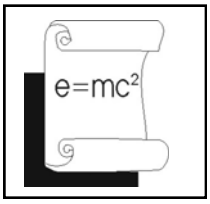
After completing this section, students will be able to define temperature, the bottom and top fixed points used, outline the features of the Celsius, Fahrenheit, Kelvin and Rankine scales as well as convert temperature values between degrees Celsius, degrees Fahrenheit, Kelvin and Rankine. Students will also know the fixed temperature values on the international temperature scale.

5.1.2 Learning Schedule



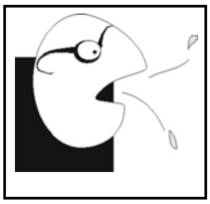
The study material for this section is available in the notes, sections 5.2 and 5.3, Chapter 5.

5.1.3 Assessment



Students will be required to define temperature, the top fixed point and the bottom fixed point and outline the features of the Celsius, Fahrenheit, Kelvin and Rankine temperature scales. Students will be expected to perform simple calculations to convert temperature values between these scales. Students should also be able to define the fixed temperature points on the international scale.

5.2 Expansion and Pressure Thermometers

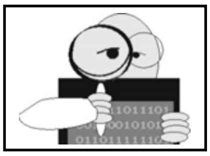


In this section, thermometers whose operation is based upon the expansion of a substance (liquid in glass and bi-metal thermometers) or the generation of a pressure within an enclosure, with increasing temperature (mercury in steel, gas filled and vapour pressure thermometers), are covered.

5.2.1 Learning Section Outcome

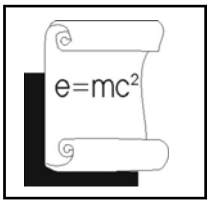
After completing this section, students will be able to sketch and describe the operation of the liquid filled thermometer (and state the liquids used in the liquid filled thermometer), the mercury in steel thermometer, the gas filled thermometer, the vapour pressure thermometer and the bi-metal thermometer.

5.2.2 Learning Schedule



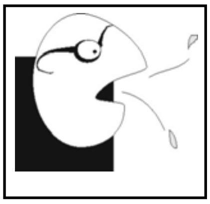
The study material for this section is available in the notes, sections 5.4 to 5.8, Chapter 5.

5.2.3 Assessment



Students will be expected to sketch and describe the operation of the liquid filled thermometer (all-glass and industrial type as well as liquids used), the mercury in steel thermometer, the gas filled thermometer, the vapour pressure thermometer and the bi-metal thermometer.

5.3 Resistance Thermometers

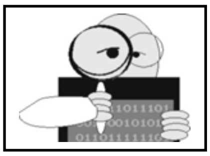


This very important thermometer, is covered in much detail in this section. Many worked examples are provided for students to study, with the aim to provide students with enhanced understanding of the underlying theory behind resistance temperature measurement.

5.3.1 Learning Section Outcome

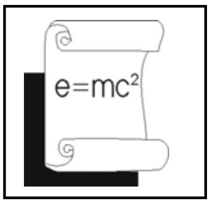
After completion of this section, students will be able to discuss the materials used for resistance thermometers, describe the structure of a resistance thermometer and discuss the measurement strategies (two, three and four wire methods) used to measure temperature with a resistance thermometer. Students will also be able to perform simple measurement calculations with regard to temperature measurement with resistance thermometers, using a Wheatstone bridge.

5.3.2 Learning Schedule



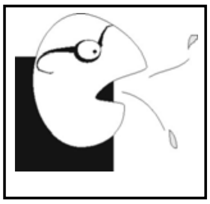
The study material for this section is available in the notes, section 5.9, Chapter 5.

5.3.3 Assessment



Students will be expected to define the temperature coefficient of resistance of a metal and discuss the general resistance/temperature properties of platinum, copper and nickel and the determination of temperature or resistance, from a given table or equation, as well as the typical construction of a resistance thermometer. Students should furthermore be able to sketch and describe and do simple calculations, involving the two, three and four wire measurement methods.

5.4 Thermocouple Thermometers

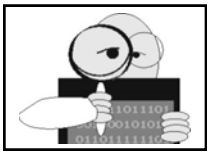


Together with resistance thermometers, thermocouple thermometers are extensively used in industry. The principle of operation is however totally different. Whereas the change in resistance of a metal with temperature is measured with resistance thermometers, thermocouple thermometers generate a temperature dependant voltage.

5.4.1 Learning Section Outcome

After completion of this section, students will be able to discuss the Seebeck effect, the thermocouple laws, thermocouple types and thermocouple thermometer construction. Students will also be able to perform simple temperature / voltage conversion problems, using a table or equation.

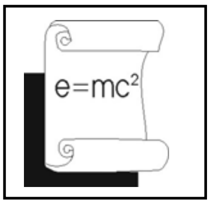
5.4.2 Learning Schedule



The study material for this section is available in the notes, section 5.10, Chapter 5.

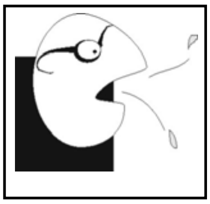
Students must complete practical assignment 7 (measuring liquid temperature by measuring thermocouple emf), that is relevant to this learning section, but forms part of unit 4.

5.4.3 Assessment



Students will be expected to define the Seebeck effect and the thermocouple laws as well as describing the different thermocouple types. Students should be able to sketch and describe the different construction strategies for thermocouples. Students should also be able to explain the reason for using extension wire and the meaning of cold junction compensation. Students must demonstrate with simple calculations, using tables or equations, that they understand how cold junction compensation is performed.

5.5 Thermistor Thermometers

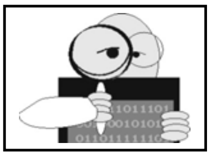


Thermistor thermometers are related to resistance thermometers in that the resistance of thermistors is used to measure temperature. Thermistors are however much more sensitive than resistance thermometers but also more non-linear with a typical negative temperature coefficient of resistance. Their temperature range is also rather limited.

5.5.1 Learning Section Outcome

After completion of this section, students will be able to discuss the essential resistance / temperature characteristics of thermistors and also the relative advantages and disadvantages of thermistors with respect to resistance thermometers and thermocouple thermometers. Students will also be able to construct a simple thermometer based on thermistor principles.

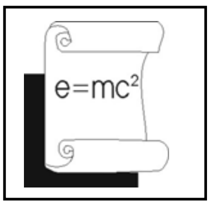
5.5.2 Learning Schedule



The study material for this section is available in the notes, sections 5.11 and 5.12, Chapter 5.

To complete this learning section, students will be required to construct a simple thermometer circuit. This project forms part of unit 3.

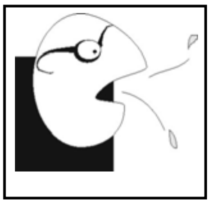
5.5.3 Assessment



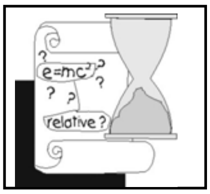
Students will be expected to discuss the general properties of thermistor thermometers and their relation to other electrical thermometers.

A project involving a thermistor thermometer, will be prepared for demonstration and assessment on the scheduled date and time. This project will form part of the assessment for unit 3.

6. LEARNING GUIDE – UNIT 2 PROCESS CONTROL



The purpose of this learning unit is to introduce students to control systems and familiarize students with typical techniques and methods used by industry to ensure good quality control of manufacturing processes.



Students should spend approximately 20 hours with this learning unit.

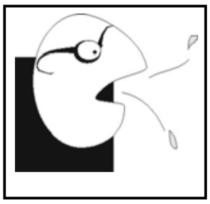
LEARNING UNIT OUTCOME

After completion of this learning unit, students should be able to:

- Define the following process control concepts:
  Controlled variable, manipulated variable and disturbance variable.
  Measured value, desired value and error value.
  Open loop and closed loop control systems.
  Feedback and feedforward control systems.
  Direct acting and reverse acting control systems.
  Dead time and first order lag in control systems.
- Explain the operation of the following control modes:
  On-off control.
  Proportional, integral and derivative control.
- Sketch and explain the operation of the following PID controllers:
  Pneumatic PID controller.
  Analog PID controllers.
  Digital PID controllers.
- Make a complete labelled drawing of a reverse acting globe style pneumatic control valve. Perform simple valve sizing calculations and explain the characteristic flow behaviour of quick opening, linear and equal percentage valves. Students will also be able to sketch and explain the operation of the following pneumatic valve components: direct acting and reverse acting actuators, globe, gate, needle, pinch, diaphragm, plug, ball and butterfly valves and a valve positioner.

INDEX

6.1 Introduction

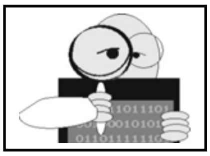


This section gives a brief history of control systems. With the aid of a water level control system students are introduced to the basic concepts behind automatic control, in particular control systems terminology, open and closed loop systems, feedback and feedforward control systems, direct acting and reverse acting control systems and process delay times.

6.1.1 Learning Section Outcome

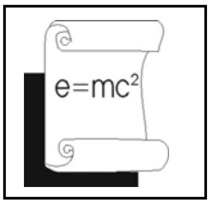
After completing this section, students will be able to define the following control system concepts: controlled variable, manipulated variable, disturbance variable, measured value, desired value and error value. Students will also be able to define and distinguish between open loop and closed loop systems, feedback and feedforward control systems, direct acting and reverse acting control systems and systems with dead time lag (distance velocity lag) and first order lag

6.1.2 Learning Schedule



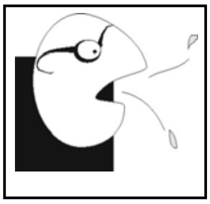
The study material for this section is available in the notes, Chapter 6, section 6.1

6.1.3 Assessment



Students will be required to define the following concepts pertaining to control systems: controlled variable, manipulated variable, disturbance variable, measured value, desired value and error value. Using a heating system or water level control system as an example, students must be competent to distinguish between open loop and closed loop control systems, feedback and feedforward control systems as well as direct and reverse acting control systems. Given the importance of automatic feedback control systems, students will be expected to sketch a labelled block diagram of a typical single input single output feedback control system. Students should also be able to sketch the response of a typical process when a step input is applied to its input and explain the meaning of dead time and first order delay in a process.

6.2 Control schemas

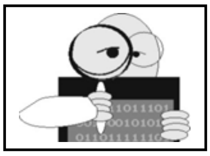


This section introduces the student to on-off control and PID control. PID control is a strategy that is used throughout industry. A water tank with level control, is used extensively in this section to assist with explaining the PID control mechanism.

6.2.1 Learning Unit Outcome

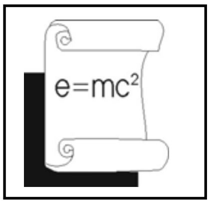
After completion of this learning unit, students will be familiar with the mechanism of on-off control as well as proportional, integral and derivative control. Students will be able to explain these control actions and give the mathematical equation that describes the control law in each case.

6.2.2 Learning Schedule



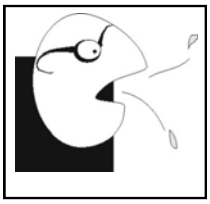
The study material for this section is available in the notes, Chapter 6, section 6.2.

6.2.3 Assessment



Students will be required to define on-off control and define the control law, proportional gain, proportional band and offset for the proportional control strategy. Students will be expected to perform simple calculations involving a proportional only control system. For the proportional plus integral control strategy, students should be able to define the PI control law, integral gain and reset time and explain the difference between proportional and proportional and integral control. For proportional plus derivative control, students must be able to define the PD control law, derivative gain and rate time. Students should be able to give the complete control law for full PID control and explain the term 'controller tuning'.

6.3 PID controllers

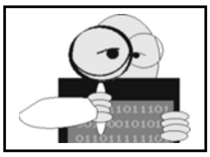


This section is a continuation of the previous section with the discussion of hardware and software methods used to implement the PID control algorithm. We start with pneumatic controllers as they were historically first used to realize the PID function. This is followed by a brief discussion of electronic and digital techniques used to generate the PID function.

6.3.1 Learning Unit Outcome

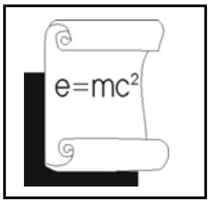
After completion of this learning unit, students will be able to give a detailed description of pneumatic PID controllers. Students will also be familiar with techniques to implement the PID function electronically and digitally.

6.3.2 Learning Schedule



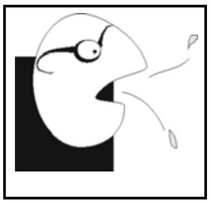
The study material for this section is available in the notes, Chapter 6, section 6.3.

6.3.3 Assessment



Students will be required to sketch and explain the operation of a complete or partial pneumatic proportional plus integral plus derivative (PID) controller. As far as the electronic PID controller is concerned, students should be able to sketch a complete or partial electronic PID controller and give an expression for the output of the operational amplifier in each of the P, I and D blocks. Students should also demonstrate that they understand the basic numerical methods used to implement the PID function digitally.

6.4 Pneumatic control valves

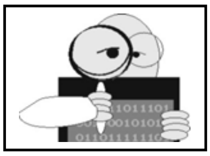


The pneumatic control valve is used as the final control element in many control loops in industry. This section introduce students to the different actuators and common valve architectures that are used. This is followed by a brief introduction to valve flow characteristics that form the basis on which valve selection for a particular service, is based. The section is concluded with a discussion of a valve positioner which is an important accessory to valve operation.

6.4.1 Learning Unit Outcome

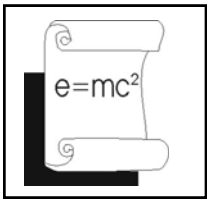
After completion of this learning unit, students will be able to make a detailed sketch of a reverse acting globe style pneumatic valve. Students will be able to distinguish between direct acting and reverse acting actuators with the aid of sketches. Students will also be familiar with all the popular styles of valve closure elements, discussing their function with sketches. Students that successfully complete this section will understand the basic flow properties of valves and be able to perform valve selection on the basis of valve flow characteristics.

6.4.2 Learning Schedule



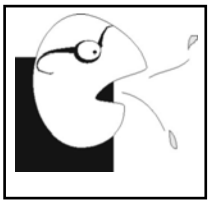
The study material for this section is available in the notes, Chapter 6, section 6.4.

6.4.3 Assessment

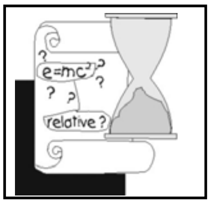


Students will be required to make a labelled sketch of a complete pneumatic control valve. Students should also be able to illustrate the difference between direct and reverse acting valve actuators. Students must be able to discuss the operation and function, with sketches, of the different valve styles: globe, gate, needle, pinch, diaphragm, plug, ball and butterfly valves. Students must demonstrate that they understand the valve flow equation and the three primary valve flow characteristics; quick opening, linear and equal percentage and that they will be able to make a tentative selection of the proper valve for a particular implementation, based on this knowledge. Finally students should be able to sketch and discuss the function and operation of a valve positioner.

7. LEARNING GUIDE – UNIT 3 EIPIN1-THERMOMETER PROJECT



The aim of this project is to give students the opportunity to apply the knowledge that they have accumulated during their study of Process Instrumentation I, to a real world measurement situation. This project will revolve around the measurement of temperature and in particular using thermistor operation.



You should spend approximately 10 hours on this project.

7.1 Project Outcome

After completion of this project, students will first of all understand how electronic components may be arranged to form a simple instrument. Secondly, students will understand how thermistors in particular are utilized as temperature sensing devices.

7.2 Project Schedule

To complete this project, students will be required to construct a simple thermometer circuit. Thermometer operation will be based on thermistor action. A common diode (such as the 1N4007) will be used as thermistor sensor. In order to measure the change in diode resistance, with temperature, a Wheatstone bridge will be utilized (please make sure that the resistors that you use are approximately 10 kΩ so that the diodes are properly biased). The thermometer circuit is shown in Figure 7-1 on page 7-2. Construction may be on pcboard, veroboard, breadboard, wood or any manner students prefer.

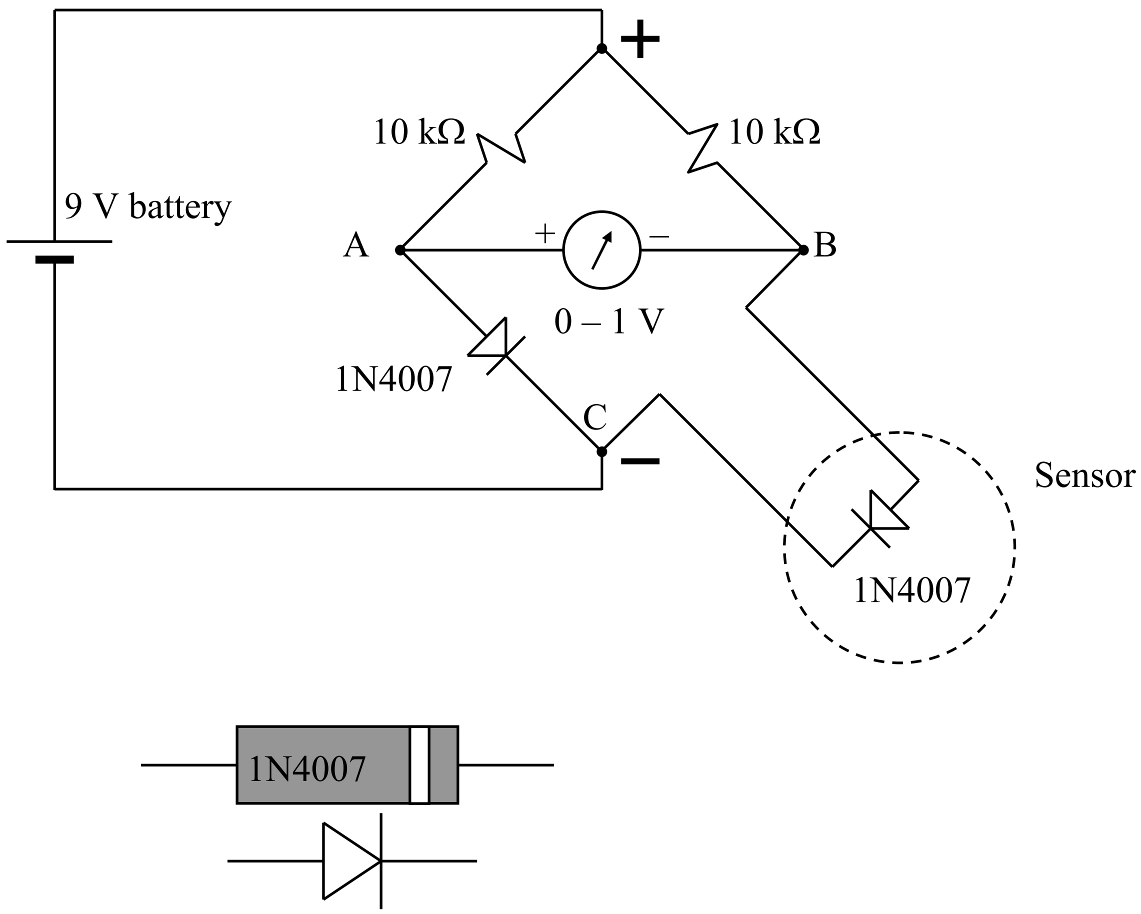


Figure 7-1

At room temperature, the forward resistances of the two diodes are approximately the same and the bridge is very nearly in balance. If the temperature of D_2 increases, its resistance will drop (more electron-hole pairs are formed to enhance conductivity with increasing temperature), causing the potential of node B to become less than the potential of node A. This voltage difference is an indication of the temperature of D_2 and is measured with a 0 - 1 V voltmeter (an analog or digital voltmeter will work ok, just mind the polarity).

(Note: It is not very important what voltage source is used, 6V, 9V or 12V. One single torch battery of 1.5V will perhaps supply a too low voltage, and the instrument's sensitivity will suffer. What is really of critical importance is that the polarity of the battery and the direction of the diodes are in the correct relation with each other as shown in the circuit diagram. If both the diodes are not forward biased, the thermometer will not operate correctly.)

7.3 Assessment

Students will prepare this project and demonstrate their work in class on the scheduled date. A very clear and well focussed colour photograph (or good quality colour computer printout), showing the project construction together with the student's student card or other identification, clearly indicating the student's name and student number, will also be prepared by each student as part of the demonstration and assessment. The photograph must be handed in during the demonstration and students must make a copy of their project photograph (before the demonstration) that will be included in their module portfolio. Students that demonstrate an operational thermometer that reacts properly to temperature changes, and submit a photograph (see for example Figure 7-2) that adequately represents their work, will receive at least 50% for unit 3.

Please note:

1. The sensor diode must not be mounted directly on the circuit (breadboard, pcboard, etc.) as damage will occur when heating the sensor. The sensor should rather be brought out a save distance from the circuit by means of rigid wires.
2. A project submitted without an accompanying photo, will not be assessed, and a photograph displayed on a camera or cell phone, will not be acceptable, as a hard copy of the photograph is needed for final assessment and moderation of the project. Students must remember to make a copy (black and white copy made on a copier machine will be adequate) of their project photo before the demonstration. Students must keep the copy of their project photo and include it into their module portfolio when preparing for unit 4 assessment.
3. It is assumed that students enrolled for the programme in electrical engineering are in possession of a digital multimeter for use in this project (otherwise students could convert a cheap milliampmeter into a voltmeter or a small analog multimeter may be purchased at an electronic shop for ±R25).
4. A thermometer sensor that does not work well, but is still sensitive to temperature changes, will be awarded 50%. A thermometer crudely constructed on breadboard or wood, see for example the prototype in Figure 7-2, that functions correctly, will receive a mark of 60%. If in addition, students that pay more attention to the construction and appearance of the project (for example building the circuit neatly on veroboard), will receive 70%. If, in addition to this, motivated and enthusiastic students that successfully attempt to calibrate the device and demonstrate an interesting method to provide for cold junction compensation (as given, the thermometer will only give a reading with respect to room temperature), will receive an assessment mark of 80% or higher, according to the judgement and discretion of the assessor.

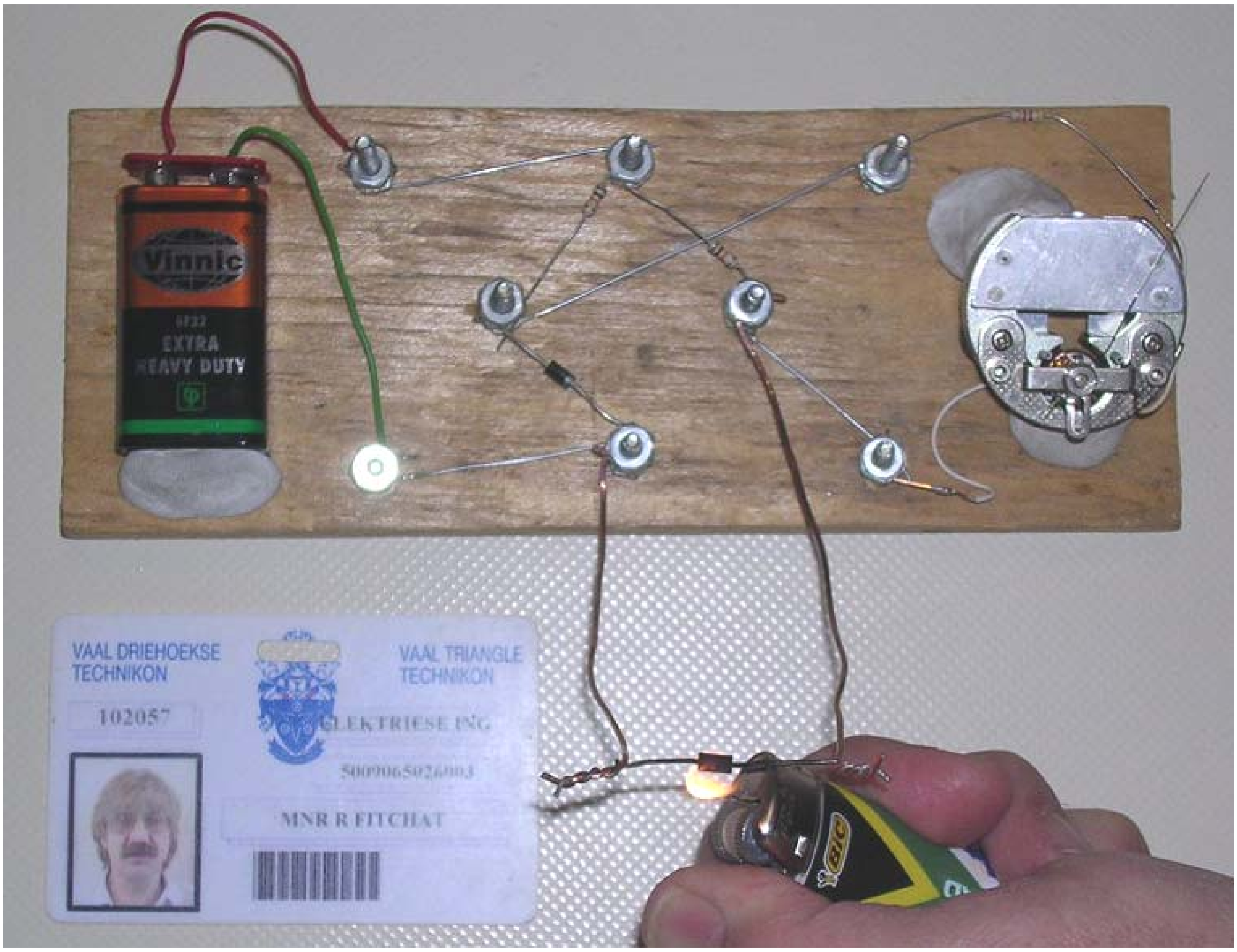
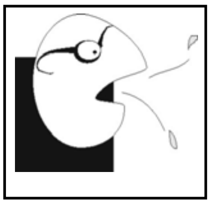


Figure 7-2

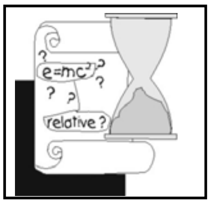
7.4 Parts List

2 × 10 kΩ resistor (¼ watt)
2 × 1N4007 diode

8. LEARNING GUIDE – UNIT 4 LABORATORY ASSIGNMENTS AND ASSESSMENT



The aim of the laboratory assignments is to give students the opportunity to use and understand the instruments that were treated during their study of Process Instrumentation I, applied in a practical environment.



You should spend approximately 15 hours on this unit.

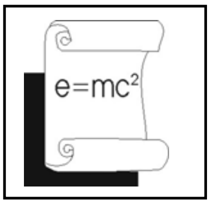
8.1 Outcome

After completion of the practical assessment, students will understand how instruments are used to measure important process variables and also gain experience with the care and calibration of instruments in an industrial or chemical industry setting.

8.2 Laboratory Schedule

The laboratory work consists of 7 experiments and the assessment guides for these experiments are attached to this learning guide. One week after an experiment was completed, each student must hand in a report, covering the goal, procedure, results and conclusions for the previous week's experiment. Each report must be labelled with the module name (Process Instrumentation I EIPIN1), year, semester and group (period A to H), as well as the name of the student and student number, with all papers of the document neatly stapled together.

8.3 Assessment



A student that does attend the practical session, takes part in the laboratory work and discussions and also hands in a well prepared report, in which the student demonstrates that the required outcome for that experiment was reached, will receive a minimum mark of 50% for that experiment. If a student hands in work of exceptional quality, he/she will receive additional marks as assessed by the assessor. If a student does not attend the practical session or does not hand in a report, the student will receive zero marks for that particular experiment.

VAAL UNIVERSITY OF TECHNOLOGY

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT PROCESS CONTROL & COMPUTER SYSTEMS

PRACTICAL GUIDE

INSTRUCTIONAL OFFERING:	Process Instrumentation I
CODE:	EIPIN1
INSTRUCTIONAL PROGRAMMES:	National Diploma: Engineering: Electrical
DOCUMENT REVISION:	October 2015
ADVISORY COMMITTEE APPROVED:	October 2009

INDEX

1 LABORATORY GUIDELINES, RULES AND PROCEDURES

All students must at all times wear long pants (or floor length skirts) and closed shoes in the laboratory.

No food and drinks allowed in the laboratory.

Students may not use any equipment in the laboratory without prior permission from the technician.

No student will be allowed to join the class if they arrive at the laboratory more than 5 minutes after start of the period.

Cell phones must be switched off before entering the instrumentation laboratory (J003).

You must at the start of your practical period inspect the equipment at the workstation and ensure that everything is fully functional. Report any problem with the equipment or damaged items immediately to the lecturer/technician in charge.

Students work individually on the practical assignments. Make sure you understand what is being done.
Students may constructively discuss the work.

In some cases a practical test will be written at a set date. The dates for the Practical tests will be discussed with the class. If required an individual report and homework should be prepared and handed in. All duplicate work will be disqualified and everybody involved will get zero %. This includes the original author's work used to duplicate from.

Preparation and presentation of all practical work will be individually assessed based on the following criteria:

- Neatness.
- Completeness of everything related.
- Initiative you show towards the practical.
- Correct wiring of the test setup if required.
- Correct configuration of the software on the computer.
- Correct operation of the test setup.
- Knowledge of the test setup when interrogated by the lecturer/technician.
- Safety considerations in the method.
- Ability to do troubleshooting and fault finding.

Students have to prepare before coming to the laboratory to do the practical work when required due to limited time available during the period.

Students that fail to comply with this and the general laboratory rules will face disciplinary steps and may be expelled from the laboratory.

Each student must sign a standard departmental safety document to accept responsibility in the laboratory.

2 Format of the practical documentation

All practical work must be computer typed and printed, or very neatly written. The following headings must be addressed. Sketches may be neatly done if a computer is not available for proper CAD presentations. All reports must have the student's surname and initials as well as the student number at the top of the first page. If a report is longer than one page all pages should be neatly stapled together.

2.1 Experiment number

The correct experiment number must be clearly stated for each experiment.

2.2 Purpose of the experiment

Briefly state the purpose of the experiment.

2.3 Apparatus

State all apparatus used during the experiment.

2.4 Methodology

Using your own words, explain step by step how the experiment was done.
If these steps are accurately repeated the results must resemble those that the student got during the experiment.
If necessary a neat diagram should be sketched, clearly showing all details of the test setup.
Label, number or name the equipment and refer to it in any explanations.

2.5 Calculations

All mathematical equations and calculations have to be clearly presented.

2.6 Results

Represent results gained from the experiments in appropriate formats, either tables, graphs or both.

2.7 Conclusions

Discuss the results and what they mean.
Describe the graphs characteristics and their response.
Where, what and why must always be addressed in the conclusion.
Repeat the outcomes and indicate their values and significance.
No calculations or graphs in the conclusion.
Results and conclusions are the most important part of the experiment.
The whole experiment is considered a failure if the student could not understand the results and could not decide how to express the conclusion.

3 INCIDENT PROCEDURE

The following procedure must be followed when an incident/accident has occurred in the laboratory:

1. Students must report incident immediately to the laboratory technician/ lecturer in charge.
2. Technician/lecturer must assess the situation and decide if the problem can be solved immediately with available tools, extinguishers, etc.
3. Technician/lecturer must then immediately contact the Safety and Health Representative (SHR) of S-Block.
4. SHR may decide to administer first aid and/or contact campus clinic if medical emergency, depending on the type of emergency.
5. SHR may also attempt to extinguish the fire and contact protection services for further assistance. Depending on the type of fire, evacuation procedures may be required and must be followed according to the designated routes.
6. Incident must be reported to the HOD as soon as possible by the SHR.
7. Incident must be reported at next Safety Committee meeting by the SHR.
8. Investigation into the incident may be conducted afterwards in order to establish better operation standards.

Experiment 1 assessment guide

Purpose: Compare the readings on a well-type manometer and a u-tube manometer using a preset pressure reading on a pressure gauge as reference. The operation of the u tube manometer and well type manometer is described by the following equations:

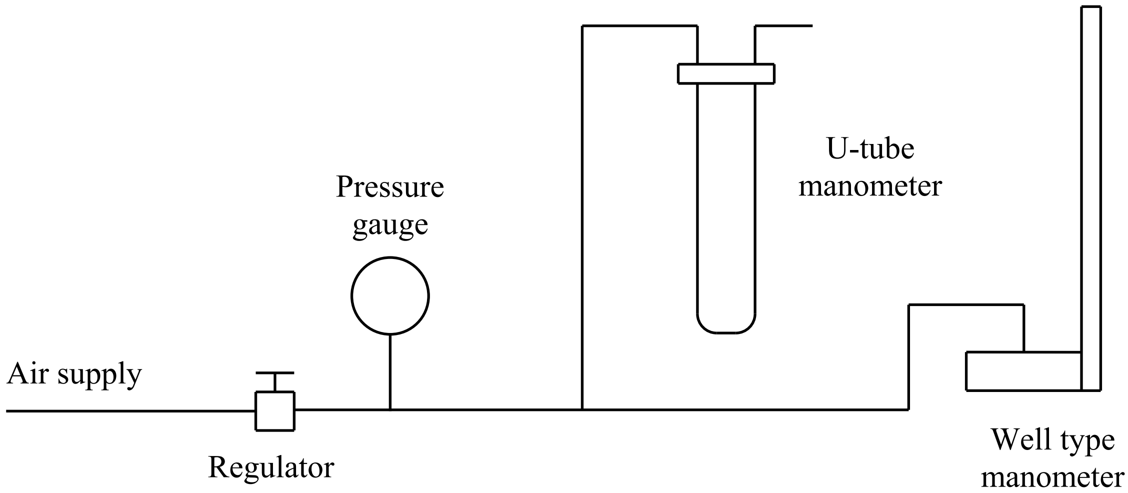
U tube: $P = \rho hg$ [Pascal] ………………….. Equation 1

Well type: $P = \rho hg(1+A_2/A_1)$ [Pascal] ……….. Equation 2

Apparatus: Pressure regulator, u-tube manometer, pressure gauge and well type manometer.

Method:

1 Connect the apparatus as shown in the sketch.



2. Slowly open the regulator until the pressure gauge reads 10 kPa. Take the pressure reading registered on the mercury u-tube manometer (millimeter) as well as on the mercury well type manometer (killopascal). Repeat this procedure for a pressure gauge reading of 20 kPa, 30 kPa, 40 kPa, 50 kPa and 60 kPa.

3. Using equation 2, calculate the height h of the mercury level in the tube of the well type manometer for each of the six kPa readings. Express h in millimeter. Show your calculation for 10 kPa in the report. Compare the h values of the well type manometer with the corresponding h values for the u tube manometer and comment on this comparison.

4. Use equation 1 to calculate the pressure in pascal that corresponds to the h values obtained for the u tube manometer (please remember to obtain h by multiplying your reading by 2 if the reading was obtained from the zero line upwards). Compare these pressure values with the pressure gauge readings.

Data for the well-type manometer: Inner diameter of well = 100 mm
Diameter of tube = 7 mm.

Experiment 2 assessment guide

Purpose: To check the calibration of a Bourdon-tube pressure gauge, using a hydrostatic test balance.

Apparatus: Hydrostatic test balance (Dead Weight Tester), pressure gauge.

Method:

1. Open the valve below the oil reservoir and close the other valve of the Dead Weight Tester.
2. Fill the system with oil by rotating the handle of the piston anti-clockwise.
3. Close the valve below reservoir, and open the other valve.
4. Apply appropriate masspieces to the platform to get a pressure reading of approximately 10% of the scale reading on the pressure gauge. (Add the mass of the platform assembly to the mass of the masspieces)
5. Rotate the handle, until the platform just starts to rise.
6. Tabulate the pressure gauge reading.
7. Add mass pieces to the platform assembly, and repeat steps 4 and 5 until maximum reading on the pressure gauge is obtained.
8. Plot the results on a graph, and determine whether the pressure gauge is accurate or not. Identify any errors present in the pressure gauge.

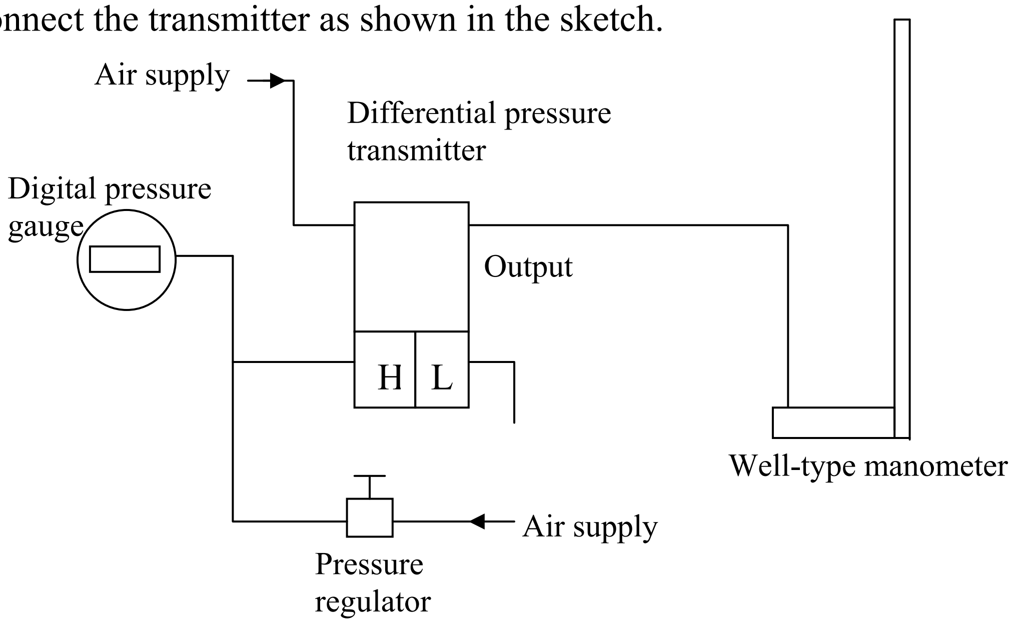
Experiment 3 assessment guide

Purpose: To calibrate a pneumatic differential pressure transmitter for an input differential pressure range of zero to one meter water (0-1 m. H_2O).

Apparatus: Foxboro model 13A D/P cell, air supply, digital pressure gauge, well-type manometer.

Method:

1. Connect the transmitter as shown in the sketch.



2. Set the air supply to 140 kPa.
3. Set the range wheel at the desired range (1 m H_2O).
4. Adjust zero screw to obtain an output of 20 kPa.
5. Apply the maximum differential pressure to the high-pressure side of the differential pressure transmitter, using the regulator and digital pressure gauge.
6. If the output of the differential pressure transmitter is not 100 kPa, note whether it is above or below 100 kPa, take off the applied differential pressure and adjust the range wheel.
(**Correct the error in the same direction that it occurs.** Example: If the output is above 100 kPa, turn the range wheel up, and if the output is below 100 kPa, then turn the range wheel down.)
7. Make sure that the zero is still 20 kPa otherwise, readjust zero to 20 kPa.
8. Repeat steps 4 to 7 until output pressure is correct at zero and maximum.
9. Apply differential pressure in steps of 25% from 0 to 100%, and plot a graph of input pressure (Y-axis) against output pressure (X-axis).

Plot a graph and write a conclusion.

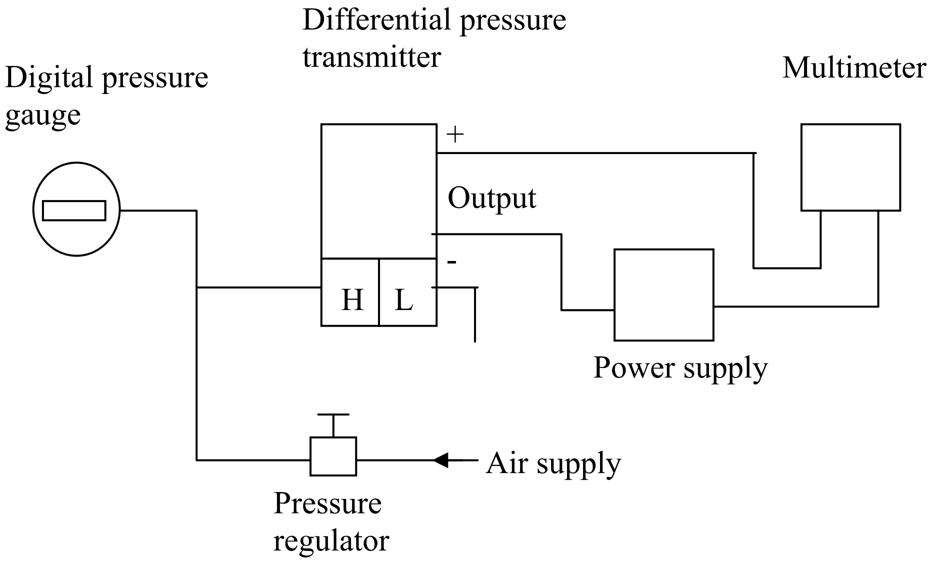
Experiment 4 assessment guide

Purpose: To calibrate an electronic differential pressure transmitter.

Apparatus: Honeywell D/P cell, power supply, multi meter, digital pressure gauge, air supply and pressure regulator.

Method:

1. Connect the electronic differential transmitter as shown in the sketch.



2. With no pressure applied to the differential pressure transmitter, set the output to 4 mA.
3. Apply a pressure of 48 cm Hg. to the high pressure side of the transmitter, using the pressure regulator and digital pressure gauge.
4. If the output is not 20 mA, adjust the range potentiometer on the electronic card.
5. Remove the air supply and repeat steps 2 to 4 until the output reading is correct at zero and maximum.
6. Apply differential pressure in steps of 25% from 0 to 100%, and plot a graph of input pressure (Y-axis) against output current (X-axis).

Plot a graph and write a conclusion.

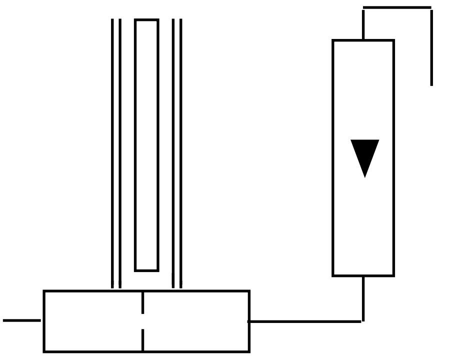
Experiment 5 assessment guide

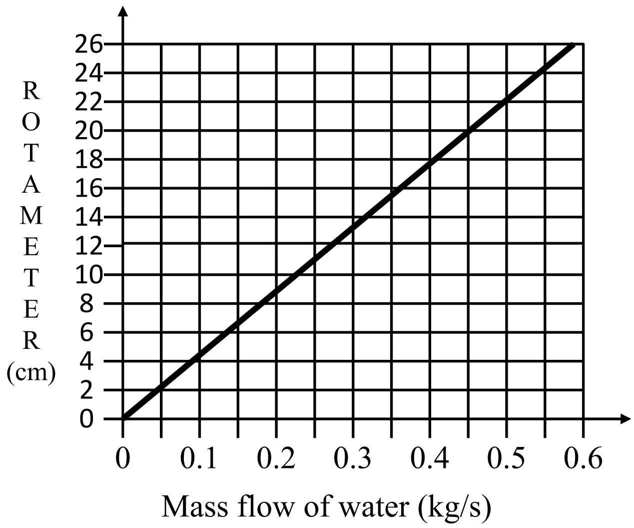
Purpose: To prove the square root relationship between the flowrate (Q) and differential pressure (h) in a flow measurement system.

Apparatus: Rotameter, differential pressure element, adjustable water supply and u-tube manometer.

METHOD:

1. Connect a water supply to a rotameter in series with an orifice plate as shown in the sketch.





2. Set the flowrate to a value of 20 cm on the rotameter and note the value of the differential pressure.
3. From the attached graph, obtain the mass flow of water for a rotameter reading of 20 cm. Convert this reading to a volumetric flow reading, by dividing the reading by the density of water. The volumetric flow reading is the value of Q in the formula: $Q = k\sqrt{h}$. Use these values, to obtain a value for k.
4. Reduce the water flow through the rotameter to any convenient value, and obtain the value for the differential pressure at that point. Tabulate the results. Use the value of k obtained in step 3 and calculate the flowrate Q.
5. Repeat step 4 a number of times and for each case, tabulate the results in the table below.

   Draw a graph of differential pressure (X-axis) against calculated flow (Y-axis).

Rotameter reading (cm)	Differential pressure (cm H_2O)	Calculated flow (m^3s^{-1})	Constant k

Experiment 6 assessment guide

Purpose: To measure the level of a container using various level measuring equipment, and compare the results.

Apparatus: Pneumatic differential pressure transmitter, electronic differential transmitter, Ekstrom gauge (Sight-glass), by-pass level transmitter, direct measurement.

Method:

1. The laboratory assistant will connect the apparatus.
2. With no liquid in the container, tabulate the output readings of the various level measuring systems.
3. Open the water supply to the container, and increase the level to 200 mm as measured on the direct measurement.
4. Tabulate the output readings of the various systems.
5. Increase the level in steps of 200 mm and repeat step 4.
6. Repeat the above mentioned steps, until the level in the container is 1 m. (maximum of container).
7. Calculate the outputs of the electronic differential pressure transmitter, by-pass level transmitter and pneumatic pressure transmitter for each case, using the following formulae, and compare it to the readings obtained during the experiment.

   (i) $I_o = (\frac{h}{h_{max}} \times 16) + 4$ mA

   (ii) $P_o = (\frac{h}{h_{max}} \times 80) + 20$ kPa

Level (mm)	Direct measure (mm)	Electronic D/P cell (mA)	Pneumatic D/P cell (kPa)	By-pass Level (mA)	Ekstrom gauge (mm)
0					
200					
400					
600					
800					
1000					

Show at least one calculation of each and write a conclusion.

Experiment 7 assessment guide

Purpose: To measure the temperature of the liquid in a container, by measuring the e.m.f. developed by a thermocouple.

Apparatus: Thermocouples (type K, J, and S). Heating bath, temperature controller, millivolt meter, temperature tables, and thermometer.

Method:

1. Fill the heating bath until the element is covered by water.
2. Adjust the setpoint of the temperature controller to 30˚C.
3. Switch on the power supply to the heating bath.
4. When the temperature of the water reaches 30˚C (as measured by the temperature controller), measure the output (mV) of the type K thermocouple, and without switching off the system move the signal wires to the type J thermocouple and wait for the water to heat up to 30 degrees Celsius again. Repeat the above step for the type S thermocouple also.
5. Adjust the setpoint of the controller to 50˚C, 70˚C and 80˚C and repeat step 4 for each temperature.
6. Measure the ambient (cold junction) temperature with a thermometer.
7. From the measured e.m.f., and using the temperature conversion tables given on Page 8-13, as well as the law of intermediate temperatures, determine the temperature of the water in the container.
8. Tabulate your results and write a conclusion.

Cold junction temperature:

Controller Temp.	Type K			Type J			Type S		
	Cold junction emf=			Cold junction emf=			Cold junction emf=		
	mV	Total. mV	Temp	mV	Total mV	Temp	mV	Total mV	Temp
30˚C									
50˚C									
70˚C									
80˚C									

Type K thermoelectric voltage (EMF in millivolt)

DEG C	0	1	2	3	4	5	6	7	8	9
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.163
30	1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571
40	1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982
50	2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395
60	2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810
70	2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225
80	3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640
90	3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055
100	4.096	4.138	4.179	4.220	4.262	4.303	4.344	4.385	4.427	4.468

Type J thermoelectric voltage (EMF in millivolt)

DEG C	0	1	2	3	4	5	6	7	8	9
0	0.000	0.050	0.101	0.151	0.202	0.253	0.303	0.354	0.405	0.456
10	0.507	0.558	0.609	0.660	0.711	0.762	0.814	0.865	0.916	0.968
20	1.019	1.071	1.122	1.174	1.226	1.277	1.329	1.381	1.433	1.485
30	1.537	1.589	1.641	1.693	1.745	1.797	1.849	1.902	1.954	2.006
40	2.059	2.111	2.164	2.216	2.269	2.322	2.374	2.427	2.480	2.532
50	2.585	2.638	2.691	2.744	2.797	2.850	2.903	2.956	3.009	3.062
60	3.116	3.169	3.222	3.275	3.329	3.382	3.436	3.489	3.543	3.596
70	3.650	3.703	3.757	3.810	3.864	3.918	3.971	4.025	4.079	4.133
80	4.187	4.240	4.294	4.348	4.402	4.456	4.510	4.564	4.618	4.672
90	4.726	4.781	4.835	4.889	4.943	4.997	5.052	5.106	5.160	5.215
100	5.269	5.323	5.378	5.432	5.487	5.541	5.595	5.650	5.705	5.759

Type S thermoelectric voltage (EMF in millivolt)

DEG C	0	1	2	3	4	5	6	7	8	9
0	0.000	0.005	0.011	0.016	0.022	0.027	0.033	0.038	0.044	0.050
10	0.055	0.061	0.067	0.072	0.078	0.084	0.090	0.095	0.101	0.107
20	0.113	0.119	0.125	0.131	0.137	0.143	0.149	0.155	0.161	0.167
30	0.173	0.179	0.185	0.191	0.197	0.204	0.210	0.216	0.222	0.229
40	0.235	0.241	0.248	0.254	0.260	0.267	0.273	0.280	0.286	0.292
50	0.299	0.305	0.312	0.319	0.325	0.332	0.338	0.345	0.352	0.358
60	0.365	0.372	0.378	0.385	0.392	0.399	0.405	0.412	0.419	0.426
70	0.433	0.440	0.446	0.453	0.460	0.467	0.474	0.481	0.488	0.495
80	0.502	0.509	0.516	0.523	0.530	0.538	0.545	0.552	0.559	0.566
90	0.573	0.580	0.588	0.595	0.602	0.609	0.617	0.624	0.631	0.639
100	0.646	0.653	0.661	0.668	0.675	0.683	0.690	0.698	0.705	0.713

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EIPINI Laboratory Assignments

Learning Guide - Unit 4

STUDENT SURNAME & INITIALS: ______________________

STUDENT NUMBER: ______________________

DEPARTMENT PROCESS CONTROL & COMPUTER SYSTEMS

SUBJECT	**Process Instrumentation I**	EIPIN1
INTRODUCTION PRACTICAL	**Introduction to the Process Instrumentation Laboratory** **Occupational Health and Safety (OHS) act.** • **Safety and laboratory procedures** • **Overview of the semesters practical work**	
SPECIFIC OBJECTIVE:	The purpose of this practical is to: • Create an awareness of basic safety and risks in the laboratory. This is the mandatory requirement as stipulated in the Occupational Health and Safety (OHS) act. • Create a general knowledge of the OHS act. • Introduce the student to the Process Instrumentation laboratory guidelines, rules and procedures. • Explain the rules for setting up the experiments. • Explain the format required for the compilation of the practical report. • Explain the homework be done as preparation for the next week's practical work. • Signing and submission of the Process Instrumentation laboratory safety rules.	

EQUIPMENT (INCLUDING, BUT NOT RESTRICTED TO THE FOLLOWING)

1 Occupational Health and Safety (OHS) act.
2 Process Instrumentation laboratory rules.
3 Laboratory student guide Process Instrumentation I.

PROCESS INSTRUMENTATION LABORATORY RULES.

1. All students must at all times wear long pants (or floor length skirts) and closed shoes in the laboratory.
2. No food and drinks allowed in the laboratory.
3. Students may not use any equipment in the laboratory without prior permission from the technician.
4. No student will be allowed to join the class after register has been taken (5 minutes after start of the period).
5. Cell phones must be switched off before entering the instrumentation laboratory (J003).
6. Every student is responsible for one's own safety in the laboratory.
7. Conduct endangering the safety of yourself or anybody else is not allowed.
8. No practical jokes are permitted in the laboratories.
9. If the laboratory equipment does not function correctly, inform the lecturer/technician of it. Do not attempt to solve the problem yourself.
10. Always use the correct equipment to reach your outcomes. This includes tools, supply leads, probes, etc.
11. Smoking is prohibited in all the venues including laboratories.

UNDERTAKING

I the above mentioned student:

- Understand these safety regulations as it has been explained to me.
- When I am in the Process Instrumentation Laboratory (J003), I will adhere to the regulations.
- I understand and accept that not adhering to these regulations will lead to my expulsion from the laboratory.

______________________________ ___ /___/_____.

Student's signature Date