Pressure measurement and calibration

Psychology, Psychotherapy

52 PRESSURE MEASUREMENT AND CALIBRATION (TH2) 53 EQUIPMENT DIAGRAMS 54 55 56 EQUIPMENT DESCRIPTION Refer to the drawing on pages 56, 57 and 58. This equipment is a bench top unit designed to introduce students to pressure, pressure scales and common devices available to measure pressure. The equipment comprises a Dead-weight Pressure Calibrator to generate a number of predetermined pressures, connected to a Bourdon gauge and electronic pressure sensor to allow their characteristics, including accuracy and linearity, to be determined.

The Dead-weight Pressure Calibrator, Bourdon gauge and pressure sensor are mounted on a common PVC base plate. The electrical console is free standing. The Dead-weight Pressure Calibrator consists of precision ground piston (10) and matching cylinder (11) with a set of weights (12). In normal use the appropriate combination of weights is applied to the top of the piston, to generate the required predetermined pressure, and then the piston is set spinning, to reduce vertical friction, while the readings from the measuring devices are recorded.

The operating range of the Dead-weight Pressure Calibrator and instrumentation is 20 kNm-2 to 200 kNm-2. The Bourdon gauge (5) and pressure sensor (6) are mounted on a manifold block (2) with a priming vessel (4) to contain the hydraulic fluid which is chosen to be water for safety and ease of use. A priming valve (7) between the reservoir and the manifold block allows the cylinder, manifold block and gauge on test to be easily primed with the water ready for use. A damping valve (8) between the cylinder and the manifold block allow the flow f water to be restricted to demonstrate the application of damping. An additional isolating valve (9) on the manifold block allows water to be drained from the manifold block or allows alternative devices to be connected for calibration. Such devices can be tested over the range 20 kNm-2 to 200 kNm-2. The Bourdon gauge (5) supplied is a traditional industrial instrument with rotary scale and mechanical indicator. The gauge has a 6” diameter dial that incorporates an arbitrary scale calibrated in degrees of rotation (independent of unit pressure) in addition to the usual scale calibrated in units of kNm-2.

A clear acrylic front face allowsobservationof the Bourdon tube the mechanism that converts motion of the Bourdon tube to rotation of the indicator needle. The electronic pressure sensor (6) supplied incorporates a semi-conductor diaphragm that deflects when pressure is applied by the working fluid. This deflection generates a voltage output that is proportional to the applied pressure. The pressure sensor should be connected to the socket (20) marked ‘ Pressure Sensor’ on the front of the console.

The power supply, signal conditioning circuitry etc are contained in a simple electrical console (15) with appropriate current protection devices and an RCD (26) for operator protection. The electrical console is designed to stand alongside the Dead-weight Pressure Calibrator on the bench top. All circuits inside the console are operated by a main on/off switch (16) on the front of the console. 57 The various circuits inside the console are protected against excessive current by miniature circuit breakers, as follows: CONT (27) O/P (28) This breaker protects the power supply and circuits inside the console.

This breaker protects the electrical output marked OUTPUT (23) at the rear of the console. The socket is used to power the IFD3 interface used for data logging. The voltage from the pressure sensor is displayed on a digital meter (17) on the electrical console. An additional conditioning circuit incorporates zero and p adjustments and allows the voltage output from the pressure sensor to be converted and displayed as a direct reading pressure meter calibrated in units of pressure. The zero control (21) and p control (22) are mounted on the front of the console for ease of use.

A selector switch (18) allows the voltage from the sensor or the direct reading pressure reading to be displayed as required. The voltage from the pressure sensor is simultaneously connected to an I/O Port (19) for the connection to a PC using an optional interface device (TH-IFD) with educational software package (TH2-303). Alternatively, the signal can be connected to a user supplied chart recorder if required. Before use, the priming vessel must be filled with clean water (preferably deionized or demineralised water) and the calibrator, Bourdon gauge and pressure sensor fully primed. 8 OPERATIONAL PROCEDURES This equipment has been designed to operate over a range of pressures from 0 kN/m2 to 200 kN/m2 may damage the pressure sensors. In order to avoid such damage, DO NOT APPLY CONTINUOUS PRESSURE TO THE TOP OF THE PISTON ROD WHEN THE PRIMING VALVE IS CLOSED except by the application of the masses supplied. An impulse may be applied to the piston when operating at a fluid pressure of less than 200 kN/m2. This procedure is described in Experiment P1.

The following procedure should be followed to prime the Dead-weight Calibrator and pressure sensors, prior to taking readings: Level the apparatus using the adjustable feet. A circular spirit level has been provided for this purpose, mounted on the base of the dead-weight calibrator. Check that the drain valve (at the back of the Bourdon gauge base) is closed. Fill the priming vessel with water (purified or de-ionized water is preferable). Open the damping valve and the priming valve. With no masses on the piston, slowly draw the piston upwards a distance of approximately 6 cm (i. . a full stroke of the piston). This draws water from the priming vessel into the system. Firmly drive the piston downwards, to expel air from the cylinder back towards the priming vessel. Repeat these two steps until no more bubbles are visible in the system. It may be helpful to raise the central section of the return tube between the manifold block and the priming vessel. This will help to prevent air being drawn back into the system as the piston is raised. Raise the piston close to the top of the cylinder, taking care not to lift it high enough to allow ir to enter, and then close the priming valve. The following procedure describes the calibration of the semiconductor pressure sensor. The procedure differs if using the optional TH-303 software, in which case users should instead refer to the Help Text provided with the software. Remove the piston from the cylinder, and switch the selector knob on the console to ‘ Pressure’. This the ‘ zero’ control on the console until the display reads zero. This sets the first reference point for the sensor calibration. Return the piston to the cylinder, and reprime the system as described above.

Place all the supplied masses onto the piston, with the greatest mass (2 ? kg) being added last. This corresponds to an applied pressure of 200 kN/m2. Spin the piston, and adjust the ‘ p’ control until the sensor output matches the applied pressure. This sets the second reference point for the calibration.

59 The calibration may be tested by applying a mass to the piston, spinning the piston in the cylinder, and then comparing the applied pressure to the sensor output. Each ? kg of applied mass corresponds to 20 kN/m2 of applied pressure. This piston itself gives an applied pressure of 20 kN/m2. 0 NOMENCLATURE FOR TH2 The following nomenclature has been used for the theory and calculations presented in this manual: Name Piston diameter Cross-sectional area Mass of piston Mass on mass piston Applied mass Acceleration due to gravity Applied force Nom d A Mp Mm Ma g F Units m m? kg kg kg m/s2 kg Type Given Calculated Given Recorded Calculated Given Recorded Definition The diameter of the dead weight calibrator piston. Cross-sectional area of dead weight calibrator cylinder. Mass of the dead-weight calibrator piston. Mass applied to piston. Ma = Mp + Mm g = 9. 1 m/s2 Force applied to fluid in system by piston and masses. F = g x Ma Pressure applied to fluid by dead weight calibrator P = F/A Ambient (atmospheric) pressure of the surroundings. Applied pressure relative to the pressure of total vacuum Needle angle taken from Bourdon gauge scale Semiconductor output taken from console display Gauge pressure taken from Bourdon gauge scale Calibrated semiconductor output taken from console display Applied pressure Barometric pressure Absolute pressure Needle angle Semi-conductor output Indicated Bourdon gauge pressure Indicated semi-conductor pressure

Pa Patm Pabs ? e Pb Ps N/m2 N/m2 N/m2 Calculated Recorded Calculated degree Recorded V N/m2 N/m2 Recorded Recorded Recorded 61 NOMENCLATURE FOR ERROR ANALYSIS The following nomenclature has been used for the error analysis presented in this manual: Name Indicated value

Actual value Range Definition Gauge reading, i. e. the pressure indicated by sensor used True pressure, pressure applied by dead-weight calibrator Total range of values covered in the results, or total range of values measurable on instrument scale.

Calculation Pi = Pb or Ps, depending on the sensor used Actual value = Applied pressure, Pa Range = Largest result – Smallest result = Pi max – Pi min or Range = Maximum possible reading – Minimum possible reading (200 kN/m? for apparatus used) No calculation. Precise data have a small scatter, indicating minimal random error ea = | Pi – Pa | ea max = ? (Pi – Pa)max? e %a = ea max X 100 Pa e%f = ea max X 100 Range Pmin = P1 + P2 + ….. + Pn n da = | Pi – Pmin| dm = da1 + da2 + … + dan n ? = da12 + da32 + … + dan2 n-1 ? Precision

How closely the results agree with each other. Actual difference Modulus of the difference between indicated value and actual value Accuracy Maximum difference between indicated pressure and actual pressure Percentage accuracy Greatest difference between of actual scale reading indicated pressure and actual pressure, as a percentage of the actual pressure. Percentage accuracy Greatest difference between of full-scale reading indicated pressure and actual pressure, as a percentage of the range. Mean Sum of results divided by number of results.

Absolute deviation Difference between a single result and the mean of several results Mean deviation Sum of the absolute deviations divided by the number of absolute deviations Standard deviation Commonly used value in analysis of statistical data 62 DATA SHEET 7 RELATIVE AND ABSOLUTE

PRESSURE The measurement of any physical property relies upon comparison with some fixed reference point. Pressure is one such property, and pressure measurement must begin by defining a suitable fixed point. An obvious reference point is that of the ambient pressure of the surroundings.

Pressure scales have been based around a zero point of the pressure of the atmosphere at sea level. Pressures lower than atmospheric are assigned negative values; pressures higher than atmospheric have positive values. Gauges for measuring pressure give readings relative to this zero point, by comparing the pressure of interest to the pressure of the surrounding air. Pressure measured with such a gauge is given relative to a fixed value, and is sometimes termed gauge pressure. Gauge measure pressure difference between the pressure to be measured and the barometric (ambient) pressure.

This may then need adjusting, to take into account any difference between barometric pressure and the pressure at sea level. Many calculations using equations derived from fundamental physical laws require absolute pressure values. Absolute pressure is the pressure relative to a total absence of pressure (i. e. a total vacuum). On an absolute pressure scale, all pressures have a positive value. The following chart illustrates the difference between gauge pressure, barometric pressure, and absolute pressure. 63

DATA SHEET 8 TECHNICAL DATA The following information may be of use when using this apparatus: Operating range of dead-weight pressure calibrator Diameter of dead-weight calibrator piston Cross-sectional calibrator area of dead-weight 20 kN/m2 – 200 kN/m2 0. 017655 m 0.

000245 m2 20 kN/m2 150 mL Pressure produced in cylinder by mass of piston with no applied masses Approximate capacity of priming vessel 64 EXPERIMENT P1 CONCEPTS OF PRESSURE AND PRESSURE SENSOR BEHAVIOUR OBJECTIVE To gain a basic understanding of the concept of pressure and its measurement.

To investigate the behavior of two kinds of pressure sensor, and the effect of damping on pressure measurement. • To gain a basic understanding of the concept of pressure and its measurement. • To investigate the behaviour of two kinds of pressure sensor • To observe the effect of damping on pressure measurement METHOD To investigate the response of two kinds of pressure sensor to a pressure applied by a dead-weight calibrator device. To investigate the response of these sensors to the application of a sudden pressure spike, with varying levels of restriction of the liquid between the pressure application and the sensor.

THEORY Pressure is the force exerted by a medium, such as a fluid, on an area. In the TH2 apparatus, pressure is exerted by a piston on a column of water. The pressure applied is then equal to the force exerted by the piston over the cross-sectional area of the fluid. The use of the piston and masses with the cylinder generates a measurable reference pressure, Pa: Pa = Fa A 65 where Fa = gMa, and Fa = force applied to the liquid, Ma = total mass (incl. piston), and A = area of piston. The area of the piston can be expressed in terms of its diameter, d, as: A = ? d2 4

The units of each variable must agree for the equations to be valid. Using SI units, Pa will be in Newtons per square metre (N/m? , also known as Pascals) if Fa is in Newtons, A is in square metres, and d is in metres. The use of specific units of pressure will be covered in exercise B. For this exercise the area of the cylinder is a constant. The pressure can therefore be considered directly proportional to the mass applied to the mass on the piston Pressure measurement is normally concerned with measuring the effects of a pressure differential between two points in a fluid.

The simplest form of pressure sensor is a manometer tube, in which a tube of fluid is exposed at one end to the first point in the fluid, and at the other to the second point. Any pressure differential causes a displacement of fluid within the tube, which is proportional to the difference. Manometers (not included with the TH2 apparatus) are cheap, simple, and can be designed to cover a wide range of pressures. However, they are best used for measuring static pressures below about 600 kN/m? , as the required height of the fluid becomes unworkable at greater pressures.

Their dynamic response is poor, so they are best suited to measuring static or slowly changing pressures. Some fluids used are toxic (such as mercury), and may be susceptible to temperature change. The Bourdon-type pressure gauge consists of a curved tube of oval cross-section. One end is closed, and is left free to move. The other end is left open to allow fluid to enter, and is fixed. The outside of the tube remains at ambient pressure. When fluid pressure inside the tube exceeds the pressure outside the tube, the section of the tube tends to 66 ecome circular, causing the tube to straighten (internal pressure lower than the ambient pressure conversely causes increased flattening, and the curve of the tube increases). A simple mechanical linkage transmits the movement of the free end of the tube to a pointer moving around dial. This type of gauge is one of the two kinds included in the TH2 apparatus. The second type of pressure gauge included as part of the TH2 is an electromechanical device. In a basic semiconductor pressure sensor, silicon strain gauges are fixed to one side of a diaphragm.

The two sides of the diaphragm are exposed to the two different pressures. Any pressure differential causes the diaphragm to expand towards the lower-pressure side, producing a change in the strain gauge voltage reading. The electronic semiconductor pressure sensor included with the TH2 is a more refined device with improved reliability and sensitivity for pressure measurement. It includes temperature compensation to reduce the effects of temperature variation on the results. The strain gauges used are formed by laying down a protective film of glass onto stainless steel, followed by a thin film of silicon.

The silicon is doped to produce semiconductor properties, and a mask is photoprinted onto it. The unmasked silicon is then removed, leaving a pattern of silicon semiconductor strain gauges molecularly bonded onto the surface of the steel. The gauges are connected to an Ohmmeter through a Wheatstone bridge, to amplify the signal produced. 67 In this type of sensor, a diaphragm is still used, but instead of fixing the strain gauges to the surface, the deflection of the diaphragm moves a steel force rod. This transfers the force to one end of the steel strip that the semiconductor resistors are bonded to.

The resulting deflection of the strip causes compression in some strain gauges, and tension in others, changing their resistance and producing a measurable output. Both the TH2 pressure sensors are set up to indicate the pressure differential between atmospheric pressure, and fluid pressurized with the use of the dead-weight calibrator. The fluid passes through a damping valve, positioned between the calibrator and the sensors. By partially closing the valve, fluid flow can be restricted. This affects the speed at which pressure is transferred from the point of application to the sensors.

EQUIPMENT SET UP Level the apparatus using the adjustable feet. A circular spirit level has been provided for this purpose, mounted on the base of the dead-weight calibrator. Check that the drain valve (at the back of the Bourdon gauge base) is closed. Fill the priming vessel with water (purified or de-ionized water is preferable). Fully open the damping valve and the priming valve With no masses on the piston, slowly draw the piston upwards a distance of approximately 6cm (i. e. a full stroke of the piston). This draws water from the priming vessel into the system.

Firmly drive the piston downwards, to expel air from the cylinder back towards the priming vessel. Repeat these two steps until no more bubbles are visible in the system. It may be helpful to raise the central section of the return tube between the manifold block and 68 the priming vessel. This will help to prevent air being drawn back into the system as the piston is raised. Raise the piston close to the top of the cylinder, taking care not to lift it high enough to allow air to enter, and then close the priming valve.

PROCEDURE This equipment has been designed to operate over a range of pressure from 0 kN/m2 to 200 kN/m2. Exceeding a pressure of 200 kN/m2 may damage the pressure sensors. In order to avoid such damage, DO NOT APPLY CONTINUOUS PRESSURE TO THE TOP OF THE PISTON ROD WHEN THE PRIMING VALVE IS CLOSED except by application of the mass supplied. An impulse may be applied to the piston when operating at a fluid pressure of less than 200 kN/m2, as is described later in this procedure. Behavior of pressure sensors Spin the piston in the cylinder, to minimize friction effects between the piston and the cylinder wall.

While the piston is spinning, record the angle through which the Bourdon gauge needle has moved, and the voltage output of the electronic sensor. Apply a ? kg mass to the piston. Spin the piston and take a second set of readings for the Bourdon gauge needle angle and the electronic sensor. Repeat the procedure in ? kg increments. When using several masses, it will be necessary to place the 2 ? kg mass on top of the other masses. Repeat the procedure while removing the masses again, in ? kg increments. This gives two results for each applied mass, which may be averaged in order to reduce the effects of any error in an individual reading.

Effect of damping Apply a single mass to the piston, and spin it. While the piston is spinning, apply an impulse to the top of the piston by striking the top of the rod once, with the flat of the hand. Watch the behavior of the Bourdon gauge needle. Note the final sensor reading after the response settles. Slightly close the damping valve. Change the mass, spin the piston again, and apply an impulse to the rod. Observe any changes in the sensor responses. Repeat the procedure, closing the damping valve a little at a time and noting the response and the final sensor reading each time.

RESULTS Tabulate your results under the following headings:- 69 Mass applied to calibrator Mm (kg) Deflection of Bourdon gauge needle (degrees) Output from electrochemical pressure sensor (mV) Notes on sensor behavior (damping) Plot a graph of sensor response against applied mass for each sensor. 70 EXPERIMENT P2 CONCEPTS OF PRESSURE MEASUREMENT AND CALIBRATION OBJECTIVE To convert an arbitrary scale of pressure sensor output into engineering units. To calibrate a semiconductor pressure sensor. METHOD To make use of a dead-weight calibrator in order to produce known forces in a fluid.

THEORY It is recommended that students read Data Sheet 1: Relative and Absolute Pressures before proceeding with this exercise. Pressure sensor calibration Variation in a pressure sensor reading may be calibrated, using known pressures, to give a gauge reading in engineering units. From exercise A, the dead-weight calibrator used in the TH2 produces a known reference pressure by applying a mass to a column of fluid. The pressure produced is Pa = F Aa where Fa = gMa, and Fa is the force applied to the liquid in the calibrator cylinder.

Ma is the total mass (including that of the piston) 71 g is the acceleration due to gravity, and A is the area of piston. The area of the piston can be expressed in terms of its diameter, d, as: A = ? d2 4 The pressure in the fluid may then be calculated in the relevant engineering units. These known pressures may then be compared to the pressure sensor outputs over a range of pressures. The relationship between sensor output and pressure may be turned into a direct scale, as on the Bourdon gauge scale. Alternatively, a reference graph may be produced.

Where the relationship is linear and the sensor output is electrical, the sensor may be calibrated using simple amplifier (a conditioning circuit). When using SI units, the units of pressure are Newtons per square meter (N/m? , also known as Pascals). To calculate the pressure in N/m? , M must be in kg, d in m, and g in m / s?. For the pressure range covered in this exercise, it will be more convenient to use units of kN/m? , where 1 kN/m? = 1000 N/m? (1 N/m? = 0. 001 kN/m?). Barometric pressure: pressure units and scale conversion Barometric pressures is usually measured in bar.

One bar is equal to a force of 105 N applied over an area of 1m?. While bar and N/m? have the same scale interval, pressure in bar often has a more convenient value when measuring barometric pressure. Pressure may also be measured in millimetres of mercury (mmHg). The pressure is given in terms of the height of a column of mercury that would be required to exert an equivalent pressure to that being measured. Another possible unit of measurement is atmospheres (atm). One standard atmosphere was originally defined as being equal to the pressure at sea level at a temperature of 15°C.

A pressure unit still ineveryday useis pounds per square inch (psi or lbf / in.?). One psi is equal to a weight of one pound applied over an area of 1 in.? If a barometer is available to measure the ambient pressure in the room where the equipment is located, the barometer reading should be converted

SI units. Pressures may be converted from one scale to another using a conversion factor. A list of conversion factors is provided below. 72 1 atm = 101. 3 x 103 101. 3 1. 013 760 14. 696 100 x 103 100 0. 987 750. 006 14. 504 133. 3 x 103 133. 3 1. 33 1. 316 19. 337 6. 895 x 106 6. 895 x 103 68. 948 68. 046 51. 715 N/m2 kN/m2 bar mmHg psi N/m2 kN/m2 atm mmHg psi N/m2 kN/m2 bar atm psi N/m2 kN/m2 bar atm mmHg 1 bar 1 mmHg x 103 1 psi x 103 ADDITIONAL EQUIPMENT REQUIRED Values for the piston diameter and weight are provided. These may be replaced by your own measurements if desired. The following equipment will be required to do so: a) Vernier callipers or a ruler, to measure the piston diameter b) A weigh-balance or similar, to measure the piston weight EQUIPMENT SET UP Carefully remove the piston from the cylinder, weigh it.

Take care not to damage the piston, as it is part of a high precision instrument and any damage will affect the accuracy of the experimental results. Level the apparatus using the adjustable feet. A circular spirit level has been mounted on the base of the dead weight calibrator for this purpose. Check that the drain valve (at the back of the Bourdon gauge base) is closed. Fill the priming vessel with water (purified or de-ionized water is preferable). Open the damping valve and the priming valve. 73 With no masses on the piston, slowly draw the piston upwards a distance of approximately 6cm (i. e. full stroke of the piston). This draws water from the priming vessel into the system. Firmly drive the piston downwards, to expel air from the cylinder back towards the priming vessel. Repeat these two steps until no more bubbles are visible in the system. It may be helpful to raise the central section of the return tube between the manifold block and the priming vessel. This will help to prevent air being drawn back into the system as the piston is raised. Raise the piston close to the top of the cylinder, taking care not to lift it high enough to allow air to enter, and then close the priming valve.

Set the selector switch on the console to ‘ Output’. PROCEDURE This equipment has been designed to operate over a range of pressure from 0 kN/m2 to 200 kN/m2. Exceeding a pressure of 200 kN/m2 may damage the pressure sensors. In order to avoid such damage, DO NOT APPLY CONTINUOUS PRESSURE TO THE TOP OF THE PISTON ROD WHEN THE PRIMING VALVE IS CLOSED except by application of the mass supplied. Conversion of an arbitrary scale into engineering units Spin the piston to reduce the effects of friction in the cylinder. With the needle still spinning, record the angle indicated by the Bourdon gauge needle.

Place a ? kg mass on the piston, and spin the piston. Record the value of the applied mass, and the angle indicated by the Bourdon gauge needle. Increase the applied mass in increment of ? kg. Spin the piston and record the needle angle each increment. Repeat the measurements while decreasing the applied mass in steps of ? kg. This gives two readings for each applied mass, which may be averaged to reduce the effect of any error in an individual reading. Calculate the applied pressure at each mass increment. Calculate the average needle angle at each pressure increment.

Repeat the experiment, this time recording the applied mass and the indicated pressure on the Bourdon gauge scale. Compare this to the average needle angle recorded previously. 74 Calibration of a semiconductor pressure sensor NOTE: This procedure differs if the TH2-303 software is being used. Please refer to the online product Help Text if using this software. Spin the piston. Record the voltage indicated on the semiconductor output display on the console. Place a ? kg mass on the piston, and spin the piston. Record the applied mass, and the voltage indicated on the semiconductor output display on the console.

Increase the applied mass in steps of ? kg, spinning the piston and recording the semiconductor output each time. Repeat the measurement while decreasing the applied mass in steps of ? kg. Calculate the applied pressure at each mass increment. Calculate the average sensor output at each pressure increment. Slowly open the priming valve. Open the valve to its maximum, and check that the damping valve is also fully open. The fluid in the system will now be at approximately atmospheric pressure (it will be slightly higher than atmospheric due to the height of fluid in the reservoir, but this is negligible compared to the range of the sensors).

Switch the selector knob on the console to PRESSURE Turn the ZERO control on the console until the display read zero, to set the first reference point for the sensor calibration. Raise the piston close to the top of the cylinder, taking care not to lift it high enough to allow air to enter, and then close the priming valve. Place a large mass on the piston, and calculate the corresponding applied pressure. Spin the piston and adjust the SPAN control until the sensor output matches the applied pressure, to set the second reference point for the calibration. Remove the masses from the piston.

Take a set of readings from the calibrated semiconductor sensor, by adding masses to the piston in ? kg increments. Repeat the reading while decreasing the applied mass. This gives two reading for each applied mass, which may be averaged in order to reduce the effect of any error in an individual reading. 75 RESULTS Tabulate your results under the following headings: Barometric pressure Mass of piston Mp Diameter of cylinder, d Cross-sectional area of cylinder, A Mass on piston Mm (kg) Applied mass Ma (kg) Applied force Fa (N) Applied pressure ………… ………… …………. ………….

Needle angle N/m2 kg m m2 Indicated Indicated SemiBourdon conductor semiconductor pressure pressure output Pb Ps Pa E ? (mV) (N/m2) (degrees) (N/m2) (N/m2) Plot graphs of average needle angle against applied pressure for the Bourdon gauge, and voltage output against applied pressure for the semiconductor sensor. Plot a graph of indicated pressure against actual pressure for the Bourdon gauge and the calibrated semiconductor pressure sensor. If there is facility for measuring barometric pressure, it is possible to calculate the absolute pressure corresponding to each applied pressure increment.

The ambient pressure of the surroundings, Patm should be measured, then converted into N/m2 (if required). An additional column should be added to the results table: Absolute Pressure, Pabs (N/m2). Absolute pressure may then be calculated as Pabs = Pa + Patm 76 EXPERIMENT P3 ERRORS IN PRESSURE MEASUREMENT OBJECTIVE To investigate the sources of error when measuring pressure. METHOD Errors in measuring a quantity, such as pressure, can come from a number of sources. Some can be eliminated by careful choice of equipment and experimental method. Other errors are unavoidable, but can be minimized.

In any experiment, it is good practice to note any possible sources of error in the results, and to give an indication of the magnitude of such errors. Errors fall into three general categories: Avoidable errors These are errors that must be eliminated, as any results including such errors will often be meaningless. Such errors include: • • • • Incorrect use of equipment Incorrect recording of results Errors in calculations Chaotic errors, i. e. random disturbances, such as extreme vibration or electrical noise that are sufficient to mask the experimental results. 7 Random errors Random errors should be eliminated if possible, by changing the design of the experiment or waiting until conditions are more favorable. Even if they cannot be eliminated, many random errors may be minimized by making multiple sets of readings, and averaging the results. Random errors include: • • • • Variation of experimental conditions (e. g. changes in ambient temperature) Variation in instrumentation performance Variation due to material properties and design (e. g. effect of friction) Errors of judgement (e. g. nconstancy in estimating a sensor reading) Systematic errors Systematic errors produce a constant bias or skew in the results, and should be minimized where possible. They include: • • • • Built-in errors (e. g. zero error, incorrect scalegraduation) Experimental errors (due to poor design of the experiment or the apparatus) Systematic human errors (e. g. reading from the wrong side of a liquid meniscus) Loading error (errors introduced as a result of the act of measurement- for example, the temperature of a probe altering the temperature of the body being measured)

Errors may also be described in a number of ways: Actual difference – the difference between the indicated value (the value indicated by the gauge or sensor) and the actual scale reading (the true value of the property being measured). The actual value must be known to calculate the actual difference. Accuracy – the maximum amount by which the results vary from the actual value. The actual value must be known. Percentage accuracy of the actual scale reading – the greatest difference between the actual value and the indicated value, expressed as a percentage of the actual value.

The actual value must be known. Percentage accuracy of the full-scale reading (total range of the measurement device) – the greatest difference between the actual value and the indicated value, expressed as a percentage of the maximum value of the range being used. The actual value must be known. Mean deviation (or probable error) – The absolute deviation of a single result is the difference between a single result, and the average (mean) of several results. The mean deviation is the sum of the absolute deviations divided by their number. The actual value is not required.

The mean deviation is an indication of how closely the results agree with each other. 78 Standard deviation (or mean square error) – the standard deviation is the square root of the mean of the squares of the deviations (‘ better’ results are obtained by dividing the sum of the values by the one less than the number of values). This is a common measure of the preciseness of a sample of data- how closely the results agree with each other. The actual value is not required. ADDITIONAL EQUIUPMENT REQUIRED Values for the piston diameter and weight are provided. These may be replaced by your own measurements if desired.

The following equipment will be required to do so: • • Vernier callipers or a ruler, to measure the piston diameter A weigh-balance or similar, to measure the piston weight EQUIPMENT SET UP To prime the cylinder, the following procedure should be followed (where this is required in the experiment): Level the apparatus using the adjustable feet. A circular spirit level has been mounted on the base of the dead weight calibrator for this purpose. Check that the drain valve (at the back of the Bourdon gauge base) is closed. Fill the priming vessel with water (purified or de-ionized water is preferable).

Fully open the damping valve and the priming valve. With no masses on the piston, slowly draw the piston upwards a distance of approximately 6cm (i. e. a full stroke of the piston). This draws water from the priming vessel into the system. Firmly drive the piston downwards, to expel air from the cylinder back towards the priming vessel. Repeat these two steps until no more bubbles are visible in the system. It may be helpful to raise the central section of the return tube between the manifold block and the priming vessel. This will help to prevent air being drawn back into the system as the piston is raised.

Raise the piston close to the top of the cylinder, taking care not to lift it high enough to allow air to enter, then close the priming valve. PROCEDURE This equipment has been designed to operate over a range of pressure from 0 kN/m2 to 200 kN/m2. Exceeding a pressure of 200 kN/m2 may damage the pressure sensors. In order to avoid such damage, DO NOT APPLY CONTINUOUS PRESSURE TO THE 79 TOP OF THE PISTON ROD WHEN THE PRIMING VALVE IS CLOSED except by application of the mass supplied. The following experiments give suggested ways in which particular sources of error may be investigated.

It is recommended that only one or two be attempted in a single laboratory session, with each being repeated several times, giving multiple samples for the error analysis. Basic Error Analysis: The accuracy of the semiconductor calibration may be investigated by performing standard error calculations on the calibrated sensor output, using the results obtained in Experiment P2. If results are not available for analysis, the following procedure should be followed: Slowly open the priming valve. Open the valve to its maximum, and check that the damping valve is also fully open.

The fluid in the system will now be at approximately atmospheric pressure (it will be slightly higher than atmospheric due to the height of fluid in the reservoir, but this is negligible compared to the range of the sensors). Switch the selector knob on the console to PRESSURE. Turn the ZERO control on the console until the display read zero, to set the first reference point for the sensor calibration. Raise the piston close to the top of the cylinder, taking care not to lift it high enough to allow air to enter, then close the priming valve. Place a large mass on the piston, and calculate the corresponding applied pressure.

Spin the piston, and adjust the SPAN control until the sensor output matches the applied pressure, to set the second reference point for the calibration.

Remove the masses from the piston. Take a set of readings from the calibrated semiconductor sensor, adding masses to the pan in ? kg increments, and again while decreasing the applied mass. This provides two set of readings for data analysis. The experiment should be repeated to provide further sets of data. Avoidable errors: Incorrect use of equipment Level the apparatus using the adjustable feet.

A circular spirit level has been mounted on the base of the dead-weight calibrator for this purpose Check that the drain valve (at the back of the Bourdon gauge base) is closed, and the damping valve is fully open. 80 Remove the piston from the cylinder, then fill the priming vessel with water (purified or de-ionized water is preferable). Close the priming valve, then replace the piston in the cylinder. Take a set of readings without priming the system first. Random errors: Friction effects Prime the system as described in the equipment set up instructions.

Tilt the board at an angle of about 5 to 10 degrees. THE EQUIPMENT BASE MUST STILL BE FIRM AND SECURE. Titling the apparatus in this way will exaggerate any friction effects, as the force applied by the piston will no longer be acting straight downwards on the column of fluids, but will have components acting at right-angles to cylinder wall. Spin the piston. Take one reading while the piston is spinning, then observe the behavior of the needle. Continue to watch the needle as the piston stops spinning, then make a note of the new gauge reading. Apply masses to the piston in ? kg increments.

At each step, spin the piston, note the sensor output, and then take a second reading after the piston stops spinning. Systematic errors: Zero error

Calibrate the semiconductor pressure sensor, but do not include mass of piston in the applied mass when calculating the applied pressure. Take a set of readings from the calibrated semiconductor sensor over a range of applied masses, now including the piston mass in the applied mass calculation. Human error Take a set or readings from the Bourdon gauge pressure scale, but stand at an angle to the dial face when taking each reading. Keep the same viewing angle for each reading.

This illustrates the effect of parallax on the readings taken. RESULTS Tabulate your results under the headings on the following page: For each result, calculate the absolute difference, ea between indicated value Pi and the applied pressure Pa. 81 Find the maximum absolute difference, the accuracy ea max and use this value and the corresponding indicated pressure to calculate the % accuracy of actual scale reading and the % accuracy of full-scale reading (use a range of 200 kN/m2). Correlate the data for several test runs, to give a set of indicated pressure readings corresponding to a single applied pressure.

Use this correlated data table to calculate the mean of the results, Pmean, the mean deviation, dm, the absolute deviation, da, and the standard deviation, ?. Errors can also be illustrated graphically: 85 Piston diameter, d = …………. m Piston mass, MP = …………….. kg Experimental conditions : …………………………………… Mass Applied Applied Applied Indicated Mean Absolute Standard Actual Accuracy % % Mean on deviation deviation deviation Accuracy Accuracy of mass force pressure pressure difference piston Actual Full result scale scale reading reading Mm dm da PI ea Emax e

%a e%f Pmin Ma Fa Pa ? kg) (kg) (kN) (kN/m2) (kN/m2) (kN/m2) (kN/m2) (kN/m2) (kN/m2) 86 Plot a graph of actual pressure against indicated pressure. On the same graph, plot a straight line showing the actual pressure. This will illustrate three characteristics of the results: • • Deviation of sensor readings from the actual value. Whether any deviation from the true reading is systematic (the graph will be a straight line or a smooth curve) or random (the graph will have no obvious relationship). Precision of the results. Precise results will be close together, not widely scattered. Precise results may still deviate strongly from the actual value. •