MSL Technical Guide 36

Calculating deadweight tester pressures

Summary

This guide describes how to calculate pressures generated by a deadweight tester, or pressure balance, for use in calibrating pressure-measuring instruments. A deadweight tester calibration certificate provides values of effective area, masses of weights and information for other correction factors required for calculating pressures generated by a deadweight tester. This guide describes how these are combined with values of local acceleration due to gravity, temperature and head correction to give pressure. Worked examples are included. The assumptions made here are valid provided that the required relative expanded uncertainty (for a 95% level of confidence) in pressure generated by the deadweight tester is 0.003 % (30 ppm) or greater.

This guide is applicable to hydraulic and pneumatic deadweight testers that generate gauge pressure, including negative gauge pressure. It is assumed that the reader knows how to calculate uncertainties in accordance with the ISO Guide to the expression of uncertainty in measurement [1]. Some of the material in this guide can also be found in other international publications relating to deadweight testers. Of particular interest are the booklet published by NPL [2] and the article by Bair [3].

Introduction

A deadweight tester is commonly used to generate known pressures for calibrating high accuracy test and reference pressure gauges, and pressure calibrators. For example, for a pressure gauge that is being calibrated by comparison with a deadweight tester according to the requirements of a Class 0.1 gauge in documentary standard EN 837-1 [4], the relative uncertainty in the pressure generated by the reference deadweight tester must be 0.025 % or less of the maximum pressure indicated by the gauge. Such uncertainties can be achieved with a deadweight tester if it is used appropriately.

The pressure-generating element of a deadweight tester essentially consists of piston-cylinder arrangement (figure 1). The combined mass of the loading weights, load table and piston, under the influence of the acceleration due to gravity g, generate a downward force F on the piston. The pressure p generated at the base of the piston (of area A) is

$$p = \frac{F}{A} = \frac{\{M_a + m_{a,T}\}g}{A} . \qquad (1)$$

where M_a is the apparent mass of the sum of the loading weights and $m_{a,T}$ is the "tare mass". Apparent mass values are calculated from measured mass values by applying a correction for fluid buoyancy, as described in the section on deadweight tester force components. The tare mass is also an apparent mass because the piston is immersed in the calibration fluid.

The area A is called the effective area because it pertains to the generation of pressure. It is somewhere in between the geometrical area of the cylinder and the piston, depending on the effect of the fluid flow between the piston and cylinder. The effective area varies with temperature t due to thermal expansion of the piston-cylinder unit. At high pressures the area may also vary significantly with pressure due to elastic distortion of the piston and cylinder. The expression for area taking into account these two factors is

$$A = A_0\left(1+\alpha_A\left[t-t_0\right]\right)\left(1+\lambda p\right) . \qquad (2)$$

In equation 2, A_0 is the effective area at the deadweight tester reference temperature t_0 (usually 20 °C) and at zero pressure. The thermal expansion coefficient of the area α_A accounts for the change in area with temperature. The elastic distortion coefficient λ accounts for changes in effective area with pressure. It is apparent from equation 2 that the corrections for thermal expansion and elastic distortion are multiplicative factors f_t and f_p, respectively, for A_0,

$$f_t = 1+\alpha_A\left[t-t_0\right] \qquad (3)$$

and

$$f_p = 1+\lambda p . \qquad (4)$$

A detailed discussion on how to incorporate corrections to force and area terms into pressure calculations is given in the following sections.

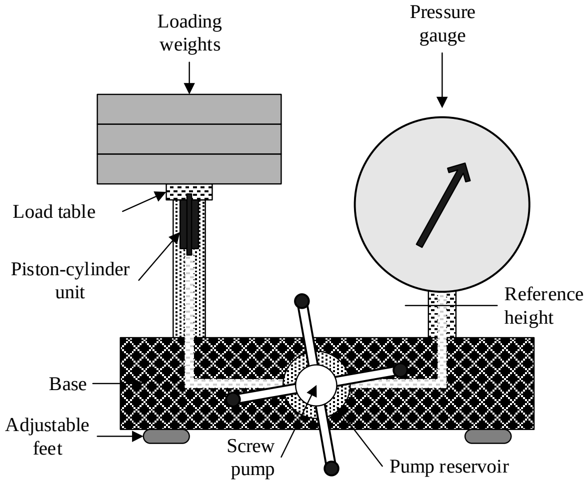

Figure 1. Schematic diagram of a deadweight tester set up for calibrating a pressure gauge.

In general, when carrying out pressure calculations, it is recommended that pressure is (at least initially) calculated in units of Pa by ensuring forces are in N (newtons) and area is in m^2. This requires (where applicable) g in $m.s^{-1}$, mass in kg, density in $kg.m^{-3}$, height in m and volume in m^3.

Deadweight tester force components

Acceleration due to gravity

A laboratory using a deadweight tester needs to know the value of g at the deadweight tester location. The value of g varies with latitude and altitude and to a lesser extent with longitude. Other variations are observed due to local variations in the structure of the earth. It is interesting to note that standard acceleration due to gravity ($g_0 = 9.80665\ m.s^{-1}$) is actually attained near Balfour in the South Island. However, in other places in New Zealand g may vary by up to 0.1 % from this value (figure 2).

The recommended method of obtaining a local value for g is to contact GNS Science [5]. GNS Science maintains the New Zealand gravity network. This will ensure that you obtain a suitably accurate value for g at the location of your deadweight tester. The relative expanded uncertainty associated with a value of g obtained from GNS will be less than 5 ppm. This uncertainty is small enough to be neglected in uncertainty calculations.

Apparent mass of loading weights

For an object of mass m and volume V that is immersed in air of density ρ_a, under the influence of gravity, the apparent m_a mass is given by

$$m_a = m - \rho_a V \ . \qquad (5)$$

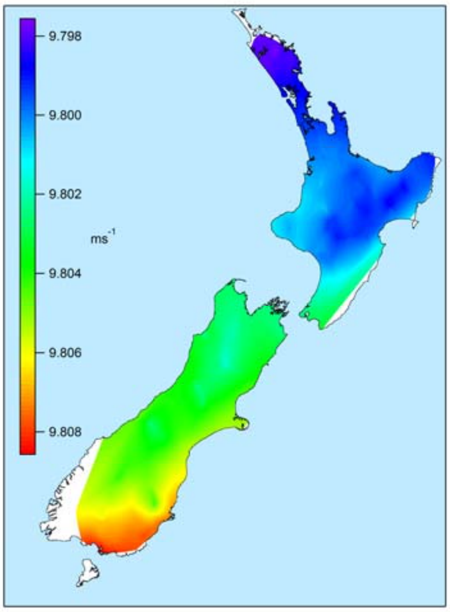

Figure 2. The variation of g throughout New Zealand.

The masses of the loading weights are determined as part of a deadweight tester calibration, with values usually reported as “conventional mass” (also called “basis 8000 mass”). The conventional mass m_C of a weight is defined as the mass of the weight of density $8000\ kg.m^{-3}$ that would balance the weight when weighed in air of density $1.2\ kg.m^{-3}$. The use of conventional mass simplifies the calculation of apparent mass and is based on the fact that most weights are made of metal of density close to $8000\ kg.m^{-3}$. The apparent mass is then given by

$$m_a = 0.99985 m_C \ . \qquad (6)$$

The relative standard uncertainty in apparent mass calculated using equation 6 is 5 ppm. This uncertainty is based on the variations in air density observed in a laboratory that is controlled to 20 ± 3 °C and for ambient pressure between 970 hPa and 1040 hPa. This uncertainty is sufficiently small that it can be disregarded.

Tare mass

Tare mass is the total apparent mass of the piston unit as well as the mass of the load table and other fixtures that are not considered as loading weights. It is important to know what this tare mass includes. In calibration certificates issued by MSL, the tare mass is reported as a conventional mass value. In this case, equation 6 is used to convert to apparent mass.

For a hydraulic deadweight tester, the hydraulic oil used for transmission of pressure forms a meniscus around either the piston or the shaft connecting the piston to the load table, depending on where the oil-air interface forms. The influence of gravity on this meniscus gives rise to an additional small downward force on the piston. In calibration certificates issued by MSL, this force is included as part of the tare mass. Some calibration providers report this component separately in the calibration certificate.

Deadweight tester area components

Thermal expansion coefficient

Most materials exhibit thermal expansion. In general, the change in area of the piston and cylinder with temperature needs to be taken into consideration in a calculation of deadweight tester pressure. Reference tables for properties of materials generally quote a linear expansion coefficient α for a material, which indicates how much a material will expand in 1-dimension. Area is a 2-dimensional quantity and for a uniform material the thermal expansion coefficient for area is $\alpha_A = 2\alpha$. Some crystalline materials are not uniform, meaning that they expand differently along different axes of the crystal lattice. In this case the thermal expansion coefficient for area is the sum of two linear expansion coefficients. For this reason the expansion coefficient for area may be denoted as (for instance) $\alpha+\beta$. Typical expansion coefficients for materials commonly used for manufacturing piston-cylinder units are shown in table 1.

Table 1. Typical values of linear (α) and area (α_A) thermal expansion coefficients for piston-cylinder materials.

Material	α / K^{-1}	α_A / K^{-1}
martensitic stainless steel	10.5×10^{-6}	21×10^{-6}
tungsten carbide	5×10^{-6} (a-axis) 7×10^{-6} (c-axis)	12×10^{-6}
low-expansion ceramic		$< 1\times10^{-6}$
Stellite	11×10^{-6}	21×10^{-6}
bronze	16×10^{-6}	32×10^{-6}

It is recommended that the calibration certificate or manufacturer's specifications for the deadweight tester are consulted to obtain a value for the thermal expansion coefficient of the effective area of the piston-cylinder unit of a deadweight tester. It may also be possible to contact the manufacturer directly. The uncertainty in a value obtained in either of these ways is generally small enough that it can be neglected in uncertainty calculations.

Guidance on correcting for thermal expansion is given below, including examples of how to proceed when the expansion coefficient is not known.

Correcting for thermal expansion

When a deadweight tester is used to calibrate a pressure-measuring device, the correction factor for thermal expansion is calculated using equation 3 based on the measured temperature of the deadweight tester during the calibration (see example 1). It is recommended that the deadweight tester temperature is measured at the start and finish of the calibration, and the average of these two values used in calculations. It is also recommended that the sensing element of the thermometer is placed in a hole or slot in a metal block that sits on the base on the deadweight tester during the calibration (see figure 3). This ensures good thermal contact between the thermometer and the deadweight tester.

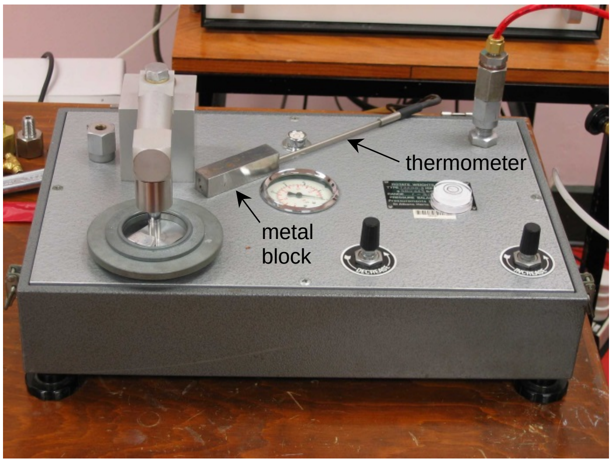

Figure 3. Measuring deadweight tester temperature with the thermometer supported in a metal block on the deadweight tester base.

There are two components of uncertainty in the deadweight tester temperature if measured in this way. The first is the uncertainty associated with a thermometer reading. If the expanded uncertainty associated with a thermometer reading is less than 0.5 °C, then it can be neglected. Note that this uncertainty must take into account whether any correction to the reading has been applied or not. The second component is the uncertainty due to the variation in deadweight tester temperature over the time of the calibration. If the laboratory environment is sufficiently controlled so that this variation is within ± 0.5 °C, then this component is also negligible.

Example 1. Correcting for thermal expansion

This example is the calculation of the temperature correction when the deadweight tester is used to calibrate a digital gauge.

The information required for this calculation is as follows:

- Thermal expansion coefficient $\alpha_A = 12\times10^{-6}$ K^{-1} (e.g. from manufacturer's specifications)
- Expanded uncertainty associated with a thermometer reading is 0.3 °C (from the thermometer calibration certificate)
- The thermometer readings at the start and finish, respectively, of the gauge calibration were 21.27 °C and 21.75 °C

The temperature t used for the calculation of the correction factor is the mean of the two thermometer readings,

$$t = \frac{(21.27+21.75)\ °\mathrm{C}}{2} = 21.51\ °\mathrm{C}\ .$$

The correction factor for the area (equation 3) is then

$$f_t = 1+\left(12\times10^{-6}\ \mathrm{K}^{-1}\times[21.51-20]\ °\mathrm{C}\right) = 1.000018\ .$$

In this example, both the uncertainty associated with a thermometer reading and the variation in deadweight tester temperature during the calibration are less than 0.5 °C. The uncertainty associated with the thermal expansion correction factor f_t can therefore be neglected.

If the thermal expansion coefficient of the effective area is not known, but the materials used for the piston and cylinder are known, then the thermal expansion coefficient can be obtained using the values in table 1. If the piston and cylinder materials are different, then the mean of the two values is taken (see example 2). The uncertainty associated with a value calculated this way is small enough that it can be neglected in uncertainty calculations.

Example 2. Calculation of thermal expansion coefficient for known piston-cylinder materials

A calibration laboratory has a deadweight tester for which the manufacturer's specifications state that the piston is made from tungsten carbide and the cylinder is made from martensitic stainless steel. From table 1, the thermal expansion coefficient is calculated as

$$\alpha_A = \frac{(12+21)}{2}\times10^{-6}\ \mathrm{K}^{-1} = 16.5\times10^{-6}\ \mathrm{K}^{-1}\ .$$

In cases where a value for the thermal expansion coefficient of the effective area cannot be obtained, the following approximate value can be used,

$$\alpha_A = 16.5 \times 10^{-6}\ \mathrm{K}^{-1}. \qquad (7)$$

This value is an average based on the range of values in table 1, and the associated standard uncertainty is 8.9×10^{-6} K^{-1}. The resulting relative standard uncertainty in pressure due to the use of this approximate value depends on the difference between the measured temperature t and the reference temperature t_0, and is given by

$$u_t = 8.9 \times 10^{-6}\ \mathrm{K}^{-1} \times \left(t - t_0\right). \qquad (8)$$

Values of this uncertainty for selected temperature differences are shown in table 2. If this uncertainty is more than one third of the standard uncertainty in pressure from the deadweight tester calibration certificate, then this uncertainty needs to be included in uncertainty calculations (see example 3).

Example 3. Calculation of uncertainty in pressure when piston and cylinder materials not known.

A laboratory is using a deadweight tester to calibrate a digital pressure gauge. The measured temperature of the deadweight tester during this calibration is t = 22.21 °C. The deadweight tester was manufactured many years ago and the laboratory cannot find any information on thermal expansion coefficients, nor on the materials from which the piston and cylinder are made. The laboratory therefore uses $\alpha_A = 16.5\times10^{-6}$ K^{-1} for the thermal expansion coefficient of the effective area.

The calibration certificate for the deadweight tester states the following:

- The reference temperature is t_0 = 20 °C
- The relative expanded uncertainty in pressures generated by the deadweight tester is 0.007 % for a 95 % level of confidence, with a coverage factor of 2.1

For this calibration of a gauge, the relative standard uncertainty in pressure due to thermal expansion is, from equation 8,

$$u_t = 8.9 \times 10^{-6}\,\mathrm{K}^{-1} \times \left(22.21 - 20\right)\,°\mathrm{C} = 1.97 \times 10^{-5} = 0.0020\ \%.$$

In order to determine if this is significant, the expanded uncertainty from the calibration certificate is first converted to a relative standard uncertainty,

$$u_{CAL} = \frac{0.007\ \%}{2.1} = 0.0033\ \%.$$

Since u_t is larger than one third of u_{CAL}, u_t must be included in the calculation of uncertainty in pressure. The relative standard uncertainty u_p in pressure generated by the deadweight tester is calculated from a quadrature sum of u_t and u_{CAL},

$$u_p = \sqrt{0.0033^2 + 0.0020^2} = 0.0039\ \%.$$

Table 2. Uncertainty in pressure due to using $\alpha_A = 16.5\times10^{-6}$ K^{-1} for a deadweight tester where a value of α_A cannot be obtained, for selected differences t–t_0 between measured and reference temperature.

t–t_0 / °C	relative standard uncertainty u_t
±1	0.0009 %
±2	0.0018 %
±3	0.0027 %
±5	0.0045 %

Elastic distortion coefficient

The calibration certificate for a deadweight tester should provide a value of the elastic distortion coefficient where elastic distortion of the piston and cylinder has a significant effect on the area of the piston-cylinder. In some cases values for elastic distortion coefficients can be found in literature provided by the manufacturer of the deadweight tester. The value of the elastic distortion coefficient will depend on the piston-cylinder design. For example in a “re-entrant” design the pressure below the piston is also applied to the outside of the cylinder. This reduces the effect of elastic distortion. In general, elastic distortion corrections are small and the uncertainty associated with a value for the elastic distortion coefficient can be ignored in pressure calculations.

The elastic distortion correction factor (equation 4) must be calculated at each measurement pressure. An approximate value p' for pressure is required in order to calculate this factor. This can be calculated using

$$p' = \frac{cg\left\{M_C + m_T\right\}}{A_0}. \qquad (9)$$

where c = 0.99985, and M_C and m_T are conventional mass values for the total mass of loaded weights and tare mass, respectively (see example 4).

A laboratory using a deadweight tester will generally have a fixed number of set pressures at which the deadweight tester is used. In this case elastic distortion corrections need only be calculated once and then applied to all subsequent measurements.

Example 4. Correcting for elastic distortion

This example is the calculation of the elastic distortion correction for the area of a deadweight tester when generating a pressure of approximately 50 MPa.

The information required for this calculation is as follows:

- The elastic distortion coefficient, $\lambda = 1.3\times10^{-9}$ kPa^{-1}
- The conventional mass of the weights loaded to generate approximately 50 MPa, M_C = 20035.57 grams
- The tare mass, m_T = 566.9 grams
- Effective area at the reference temperature and at zero pressure, A_0 = 4.03251 mm^2
- Acceleration due to gravity, g = 9.8028 m.s^{-1}

To proceed with the calculation, area and mass terms are first converted to suitable units

- A_0 = 4.03251 mm^2 = 4.03251×10^{-6} m^2
- M_C = 20035.57 grams = 20.03557 kg
- m_T = 566.9 grams = 0.5669 kg

An approximate value of pressure is calculated using equation 9 and then converted to units that match those of the elastic distortion coefficient,

$$p' = \frac{0.99985 \times 9.8028 \times (20.03557 + 0.5669)}{4.03251 \times 10^{-6}} .$$
$$= 5.00759 \times 10^{7}\ \text{Pa} = 50075.9\ \text{kPa}$$

The elastic distortion correction factor is then (from equation 4)

$$f_p = 1 + \left(1.3 \times 10^{-9}\ \text{kPa}^{-1} \times 50075.9\ \text{kPa}\right) = 1.000066 .$$

Head correction

Consider a gauge that is connected to the port of the deadweight tester by way of a vertical tube. The pressure exerted by the fluid column within the tube causes the pressure at the top of the column (the gauge port) to be less than that at the bottom (the deadweight tester port). A deadweight tester calibration certificate reports the pressure generated at the deadweight tester reference position, which is usually the top of the deadweight tester outlet port. To calculate the pressure at the gauge port, a correction must be made to account for any “head” of fluid. This correction (the head correction) is

$$p_h = -\rho_f g h \qquad (10)$$

where ρ_f is the fluid density and h is the height of the gauge port above the deadweight tester reference position. If the gauge port is below the reference position then h will be a negative number. If density is in units of kg.m^{-3}, h in m and g in m.s^{-1}, then the head correction will be in Pa (see example 5). Table 3 shows typical fluid densities for fluids used in deadweight testers. Oils used in hydraulic deadweight testers are usually light to heavy duty mineral oils (ISO viscosity grades 10 – 68 [6]). For pneumatic deadweight testers the head correction is more complex because gas density varies with pressure. The equation in table 3 is used in this case.

Example 5. Head correction (hydraulic deadweight tester)

This example is the calculation of the head correction when a hydraulic deadweight tester is used to calibrate a gauge. The gauge port is 320 mm above the reference position of the deadweight tester.

The information required for this calculation is as follows:
- The measured density of the hydraulic oil is 860 kg.m^{-3}
- The calculated pressure at the deadweight tester reference position is 50.0717 MPa
- The acceleration due to gravity, at the location of the laboratory, is g = 9.8028 m.s^{-1}

Converting height to recommended units, h = 0.32 m, the head correction is then

$$p_h = -860\ \text{kg.m}^{-3} \times 9.8028\ \text{m.s}^{-1} \times 0.32\ \text{m} = -2697\ \text{Pa}$$
$$= -0.0027\ \text{MPa} .$$

The pressure at the gauge port is then

$$p = 50.0717\ \text{MPa} - 0.0027\ \text{MPa} = 50.0690\ \text{MPa} .$$

Table 3. Typical deadweight tester fluid densities.

Fluid	density ρ_f / kg.m^{-3}
hydraulic oil	870
distilled water	1000
sebacate calibration fluid	900
air (for p in Pa, t in °C)	$\frac{0.00347 \times p}{(273.15 + t)}$

Wherever possible, try to position the gauge so that its vertical height is sufficiently close to the height of the deadweight tester port so that a head correction is not necessary. For pneumatic deadweight testers, the head correction, as a fraction of pressure, varies by −0.12 ppm per mm of height above the deadweight tester reference port. This is due to the dependence of air density on pressure (table 3). Based on this relationship, the head correction for pneumatic deadweight testers can be disregarded if h is within ±40 mm.

For hydraulic deadweight testers, a head correction may be required. Criteria for ensuring that there is no significant error in the head correction for hydraulic fluids are given in table 4. These criteria are indicative only and in some cases a specific calculation may give a more appropriate tolerance for height measurement.

Table 4. Criteria for ensuring negligible error in head correction with hydraulic fluids (h < 250 mm). Standard uncertainty in deadweight tester pressure is u_{CAL} and standard uncertainty in measured height is u_h.

	Pressure	
u_{CAL}	3 – 10 MPa	> 10 MPa
0.0015 %	u_h < 1 mm, use measured ρ_f	u_h < 5 mm, ρ_f from table 3
0.0025 %	u_h < 1 mm, ρ_f from table 3	u_h < 10 mm, ρ_f from table 3
0.005 %	u_h < 3 mm, ρ_f from table 3	u_h < 25 mm, ρ_f from table 3

Uncertainty calculation

The aim of this guide is to provide guidance on how to minimize, wherever possible, the effort required in calculating uncertainty in pressure generated by a deadweight tester. Changes in effective area and mass values over the period between successive calibrations may also contribute to uncertainty. If a deadweight tester is maintained correctly, and is handled with appropriate care (including the loading weights), then these changes are usually sufficiently small to be neglected in uncertainty calculations. However, it is essential to confirm this after a deadweight tester has been recalibrated. This can be done by comparing pressure values calculated using the new and previous calibration values, for a range of pressures over which the deadweight tester is used.

Pressure calculation

This section contains a worked example of calculation of the pressure generated by a hydraulic deadweight tester and its associated uncertainty. For brevity, results from earlier examples in this guide have been utilised in the calculation.

Example 6. Pressure calculation (hydraulic deadweight tester).

In this example a hydraulic deadweight tester is used to calibrate a digital gauge. Calculations are for a nominal pressure of 50 MPa. This example illustrates the calculation of pressure where corrections for thermal expansion, elastic distortion and pressure head are applied.

The information provided in the calibration certificate for the deadweight tester is based on the following equation for calculating pressure at the deadweight tester reference position,

$$p = \frac{cg\{M_C + m_T\}}{A_0\left(1+\alpha_A[t-t_0]\right)(1+\lambda p)} . \qquad (11)$$

The information obtained from the deadweight tester calibration certificate for this calculation is as follows:

- Effective area at t_0 = 20 °C, A_0 = 4.03251 mm^2
- Tare mass (a conventional mass), m_T = 566.9 grams
- Sum of conventional mass of weights for a nominal pressure of 50 MPa, M_C = 20035.57 grams
- Air buoyancy correction factor c = 0.99985
- Thermal expansion coefficient $\alpha_A = 12\times10^{-6}$ K^{-1}
- Elastic distortion coefficient $\lambda = 1.31\times10^{-9}$ kPa^{-1}
- The relative expanded uncertainty in pressure from the calibration is 0.007 % with a coverage factor of 2.1. This uncertainty includes uncertainties in masses of loading weights, tare mass and effective area

The measurement conditions that apply to the calibration at this pressure value are as follows:

- A value of g = 9.8028 m.s^{-1} for the acceleration due to gravity was obtained from GNS Science
- The temperature measurements and thermal expansion correction factor are the same as for example 1. The thermal expansion correction factor is therefore f_t = 1.000018
- The elastic distortion correction factor at 50 MPa is f_p = 1.000066 (from example 4)
- The gauge port is at a height of 320 mm above the height of the deadweight tester reference port. The head correction required to calculate the pressure at the gauge port is p_h = –0.0027 MPa (from example 5)

To proceed with the pressure calculation, area and mass terms are first converted to suitable units,

- A_0= 4.03251 mm^2 = 4.03251×10^{-6} m^2
- M_C = 20035.57 grams = 20.03557 kg
- m_T = 566.9 grams = 0.5669 kg

To calculate pressure, the force and area terms (numerator and denominator in equation 11, respectively) are considered separately. The force is

$$F = 0.99985\times 9.8028\ \text{m.s}^{-1}\times\{20.03557\ \text{kg} + 0.5669\ \text{kg}\}$$
$$= 201.9316\ \text{N}.$$

The effective area is for this measurement is

$$A = 4.03251\times10^{-6}\ \text{m}^2\times1.000066\times1.000018$$
$$= 4.032849\times10^{-6}\ \text{m}^2 .$$

The calculated pressure at the deadweight tester reference position is then

$$p = \frac{201.9316\ \text{N}}{4.032849\times10^{-6}\ \text{m}^2} = 5.00717\times10^{7}\ \text{Pa}$$
$$= 50.0717\ \text{MPa} .$$

Finally the head correction is applied to give the pressure p_G at the gauge port,

$$p_G = 50.0717\ \text{MPa} - 0.0027\ \text{MPa} = 50.0690\ \text{MPa} .$$

For this example, as explained in this guide, the uncertainty in p_G is simply the uncertainty in pressure from the deadweight tester calibration certificate, i.e. a relative expanded uncertainty of 0.007 %.

References and Bibliography

[1] *Guide to the expression of uncertainty in measurement* JCGM 100:2008 (BIPM, 1st edition, 2008)

[2] S Lewis and G Peggs, *The pressure balance – a practical guide to its use*, National Physical Laboratory (NPL), London, 1992.

[3] M Bair, *An examination of the uncertainty of industrial deadweight testers used for pressure calibrations in different environments*, NCSLI Measure J. Meas. Sci. Vol. 8 pp. 28-34, 2013.

[4] *Pressure gauges – Part 1: Bourdon tube pressure gauges – Dimensions, metrology, requirements and testing*, EN 837-1, December 1996, CEN

[5] GNS Science can be contacted at www.gns.cri.nz

[6] *Industrial liquid lubricants - ISO viscosity classification,* ISO 3448:1992, International Organization for Standardization.

Further information

If you want to know more about deadweight tester calculations, contact MSL and book in for a Pressure Calibration Workshop. See the MSL website http://msl.irl.cri.nz.

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