MSL Technical Guide 16

Care and Use of a Deadweight Tester

Summary

This technical guide describes some simple procedures for the care and use of a deadweight tester. Maintenance of the operating fluid and weights are covered along with procedures for regular performance testing of the instrument spin and fall rates.

Introduction

Deadweight testers, pressure balances and piston gauges, are piston-cylinder based instruments used to generate reference pressures. Typically, they are used for pressure gauge calibrations [1]. Deadweight testers are stable instruments with long recalibration intervals (up to five years). The instrument has to be well maintained to assure the quality of its performance.

A deadweight tester consists of a precision piston-cylinder unit that defines an area A and loading weights that apply force F so the generated pressure P is given by $P = F/A$. The loading weights and piston normally rotate to ensure that the piston does not touch the cylinder. The resulting low friction makes the instrument very repeatable. Fluid slowly leaks out though the piston-cylinder gap.

The operating fluids are either gas (air, nitrogen) or liquid (oil). Gas operated instruments typically operate over a lower pressure range (<10 kPa to 10000 kPa) while liquid instruments operate at higher pressures (1 MPa to >200 MPa). The pressure range for gas is restricted due to the hazard caused by high-pressure gas; the high gas compressibility can store a large amount of energy. Liquids such as oil are much less compressible so present a lower risk.

Operating Fluid

Fluid cleanliness and properties, such as viscosity, density and lubrication, are important. Ensure you are using the fluid recommended by the manufacturer and that the same fluid is used when the deadweight tester is calibrated.

Gas instruments use either atmospheric air with a hand pump or compressed gas, such as nitrogen, contained in a cylinder. When using gas from a cylinder we recommend a grade of nitrogen gas that has been analysed to ensure low levels of impurities (for example, “zero grade nitrogen”).

Cleanliness of the gas supply is very important. Gas operated instruments are difficult to operate and can require frequent cleaning. This work is reduced if both the gas supply and tubing are dry and free of any impurities. Small particles can get into the gap between the piston-cylinder causing a dramatic loss of sensitivity. The presence of liquids, such as oil, water or even water vapour, in the gas can cause problems by condensing in the piston-cylinder gap.

Liquid operated instruments normally use hydraulic oil (hydrocarbon or synthetic). The oil viscosity is important as it affects both the leak rate and spin time of the piston-cylinder unit. Oil instruments are generally more reliable than gas operated instruments.

Oil operated instruments are maintained by changing the oil frequently and cleaning out the oil reservoir. Regularly pumping oil out of the gauge port is a good way to prevent contamination from reaching the piston-cylinder unit. Use fresh oil (check the expiry date) and store in containers that keep out air, moisture and light.

The gauge connection is the main source of contamination in an oil-operated deadweight tester. Oil from the instrument enters the gauge when generating pressure, and mixes with fluid inside the gauge. Some of this contaminated oil may be taken back into the reservoir when the pressure is released. A number of steps can be taken to minimise this risk:

- Clean out the gauge before connecting it to your system. Do this by gently blowing air into the gauge port via a thin tube. Take care to avoid damaging the gauge mechanism.
- Pump oil out of the gauge port after each gauge calibration to flush out any contaminated oil.
- Connect a long section of tube between the gauge and deadweight tester. This prevents oil from the gauge entering the deadweight tester. Regularly flush oil through this tube. Keep the gauge height the same as the gauge port to avoid errors due to the head correction.
- Use a liquid/liquid separator. A liquid/liquid separator consists of a weak diaphragm that transmits the pressure while keeping the fluids from the deadweight tester and gauge separate. The pressure drop across the diaphragm must be measured and its uncertainty combined with the uncertainty of the generated pressure [1].

We recommend cleaning each gauge using air along with pumping fluid out of the gauge port after each calibration. Liquid/liquid separators are more labour intensive and increase the uncertainty of the generated pressure.

Care of Weights

Most weights are made of stainless steel. The care of these weights falls into three areas: storage, handling and cleaning.

Store the weights in a clean dry area and cover them when not in use (such as a cloth dust cover). Stack the weights so they can be lifted without scraping against each other. For example, circular weights can be in racks on their edge so they can be rolled in and out.

Most deadweight tester weights are handled with clean bare hands but always use gloves when handling high accuracy pressure balance weights. As a rule of thumb, gloves should be used when handling weights for instruments that have calibration uncertainties of 0.02 percent or less.

Limit cleaning of the weights to wiping with a clean dry cloth. Do not use an abrasive cloth or cleaner. Weights from oil-operated deadweight testers often have a light coating of oil from repeated handling. Again, a wipe with a clean dry cloth should be sufficient to ensure the mass remains within its calibration uncertainty. Keep the weights in the same condition they were in when they were calibrated.

Performance Monitoring

We recommend regularly measuring the spin time and fall rate of the piston-cylinder unit. The spin time is the total time the piston spins at a given load. The fall rate is the time it takes the piston to fall through a given change in height (this is equivalent to the leak rate in the piston-cylinder gap). Both these simple measurements provide information about the condition of the piston-cylinder unit and operating fluid.

Carry out these measurements about quarterly and plot the results on graphs to monitor long-term trends. A spin test should also be carried out each day a gas-operated instrument is used to check that the piston is spinning freely in the cylinder.

Spin Time Monitoring

The spin time is a measure of how freely the piston rotates in the cylinder and of the friction in any load table bearings. The measurement procedure is as follows:

1. Lightly load the deadweight tester with just enough weight so it will spin and come to rest in a short time, about 1 minute is convenient. For gas-operated instruments, this is often just the piston and load table while oil operated deadweight testers may require up to 10 % of the full load. Once the load is determined, use this load for all future spin time tests.

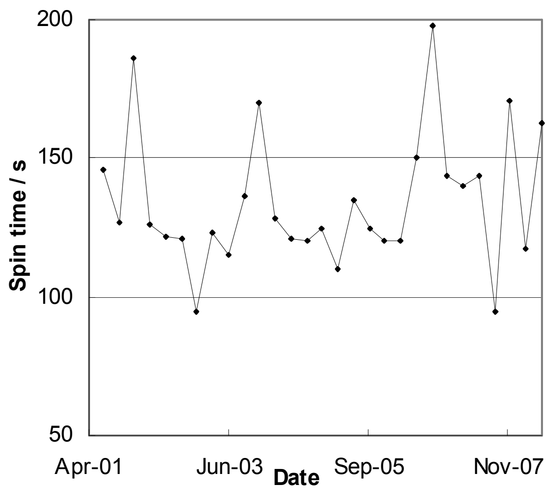

Figure 1. Spin time measurements for an oil-operated instrument, load 2 percent of full load.

2. Pressurise the instrument and set the load spinning at a reasonable rotation rate, i.e. about 1 revolution per second. Try to spin the instrument at the same rate for each test, although this is not too critical. Ensure that the weights can rotate freely; you may have to disconnect the motor drive if present.
3. Use a stopwatch to measure the time it takes the weights to stop rotating.
4. Take note of how the weights stop spinning. Ideally, the weights should slow down quietly and smoothly, and continue to spin at very low rates.

Figure 1 shows spin time data for an oil-operated deadweight tester recorded over several years. A typical spin time for an unloaded gas deadweight tester will be in the range 1 to 4 minutes and an oil-operated deadweight tester will require a load of between 2 percent and 10 percent to spin for more than 1 minute.

Set a minimum and maximum spin time for the instrument. If the spin time falls outside these limits then the piston-cylinder unit requires attention. Spin time measurements are variable so use the data you have collected to find the normal operating range. For the deadweight tester shown in Figure 1 a minimum spin time would be about 100 s while the maximum spin would be > 200 s. The minimum spin time is the more important limit as short spin times affect the sensitivity of the instrument.

A reduction in spin time may indicate contamination in the piston-cylinder gap. This will cause the piston to come to an abrupt halt. Clean the piston-cylinder, the deadweight tester tubing and reservoir.

An increase in spin time may indicate that the oil is contaminated with a lower viscosity fluid (i.e. water); this also increases the fall rate. Change the oil in the reservoir and instrument tubing and either clean the piston-cylinder unit or pressurise with the new oil and wait until the lower viscosity oil leaks out.

Fall Rate Monitoring

The fall rate is the downward velocity of the weights when the instrument is generating pressure. The fall rate is directly related to the rate fluid leaks through the piston-cylinder gap. The measurement procedure is as follows:

1. First, choose a pressure where there is a readily measured fall rate. Often this will be between the mid range pressure and the top pressure. Aim to measure a change in height of 3 to 5 mm to ensure reasonable measurement accuracy but limit the total measurement time to a maximum of 5 minutes if the deadweight tester has a very low fall rate.
2. Load the required weights and pressurise the instrument.
3. Set the weights spinning and wait until the fall rate stabilises. This may take several minutes, especially if the pressure is above 10 MPa, due to thermal changes and air dissolving into the oil.
4. Adjust the operating height so that the piston is a few millimetres above the middle operating point.
5. Position a ruler near the edge of the weights so that you can measure their height, see Figure 2. Measure from the top edge of the mass stack to avoid confusion when re-measuring the height.
6. Record the start height and start the stopwatch.

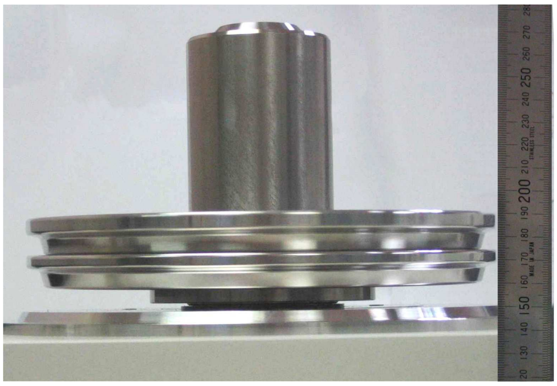

Figure 2. Measuring the fall rate of a gas-operated deadweight tester.

7. Record the stop height and stop the stopwatch.
8. Finally calculate the fall rate using Fall rate = (Start height − Stop height) / Time.

Example fall rate calculation: The height measurements show that the weight stack fell 3 mm in 195 s. The fall rate is calculated to be 3 mm / 195 s = 0.015 mm/s, this can be written as 0.015 × 60 = 0.92 mm per minute.

Typical fall rates for both gas and oil operated deadweight testers fall in the range 0.1 to 3 mm/min, depending on the design and operating pressure. Use your initial measurements to establish a baseline for the deadweight tester performance and plot the measured data to detect long-term trends. Figure 3 shows fall rate measurements made on a gas operated deadweight tester over several years.

An increase in the fall rate may indicate:

- A leak in the pressure line. Check the tubing and fittings both inside and outside the instrument. Also, check the seals in the pump, piston-cylinder unit and valve stems.
- The fluid viscosity is too low. Check to see if the spin time has increased. Ensure you have the correct fluid and that it is clean (i.e. check for water mixing with oil).
- Wear in the piston-cylinder gap. Check to see if the spin time has increased. Review your cleaning and handling methods, contact MSL for advice.

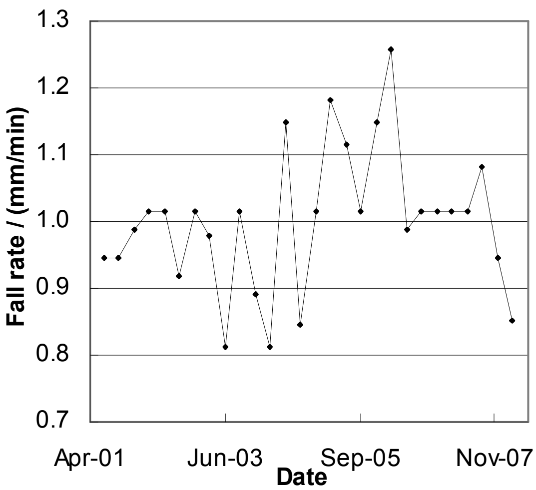

Figure 3. Fall rate measurements for a gas-operated deadweight tester at full load.

A decrease in the fall rate may indicate:

- The fluid viscosity is too high; check to see if the spin times have decreased as well. Clean the instrument and ensure you have the correct fluid.
- Contamination in the piston-cylinder gap. This will also show up as reduction in the spin time. Clean the piston-cylinder, the deadweight tester tubing and reservoir.

Cleaning the Piston-Cylinder Unit

Care needs to be taken to avoid damage when cleaning a piston-cylinder unit. Piston-cylinder units are precision mechanical devices with tight manufacturing tolerances, a high surface finish and small clearances. Poor handling and cleaning can destroy this expensive unit.

Gas operated units will require more frequent cleaning while oil operated units rarely require cleaning if well maintained.

We recommend following the manufacturer's cleaning procedure in the first instance. Find this in the operating manual or obtain it directly from the manufacturer.

A typical cleaning procedure is outlined below. In this procedure, the piston-cylinder unit is removed from the instrument and the piston is taken out of the cylinder. Some gas-operated units can be cleaned without taking the piston out of the cylinder, check your operating manual.

The procedure is as follows:

1. Study the instrument manual and drawings if available.
2. Remove the piston-cylinder unit from the instrument housing.
3. Take the unit to a clean tidy work area.
4. Use gloves (powder free and lint-free), or use lint-free tissues, to avoid directly touching the piston-cylinder surfaces.
5. Identify the top end of the piston and cylinder.
6. Remove the piston from the cylinder. Do this by placing the cylinder on the bench and pull the piston vertically upwards in a continuous movement, leaving the cylinder behind. Keep the piston vertical to prevent the piston jamming as it leaves the cylinder.
7. Clean the piston and cylinder in separate beakers containing solvent. Choose a solvent that dissolves the operating fluid, removes dirt, does not attack the piston or cylinder surfaces and does not leave a residue on the surfaces. Place each beaker into an ultrasonic bath (this may be filled with water) and clean for several minutes.
8. If an ultrasonic bath is not available then use laboratory grade tissues, such as a lens cleaning tissue, soaked in the solvent. Clean the components by wiping and then wash the piston and cylinder by squirting solvent over the surfaces.
9. Dry all parts using clean gas or air from a puffer bottle.
10. Follow the manufacturer's instructions when re-assembling the unit:
    - Gas deadweight testers are normally assembled dry but check the manufacturer's instructions.
    - For oil-operated units cover both the piston and cylinder mating surfaces in oil before assembly.

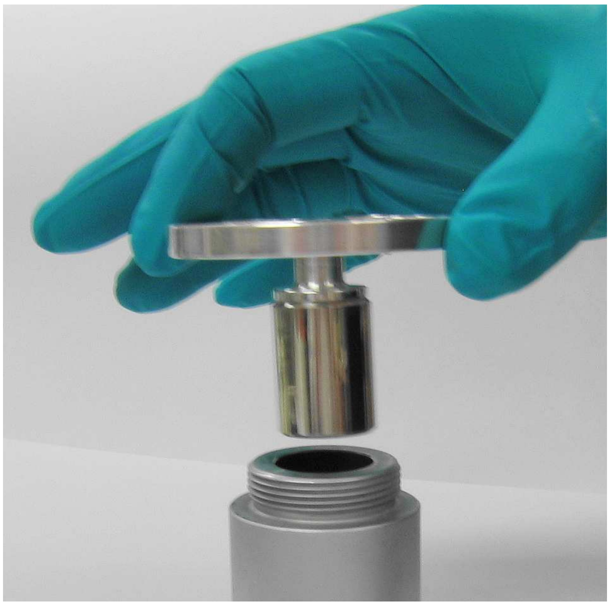

Figure 4. Lowering a piston into the cylinder of a gas-operated deadweight tester.

- To reassemble first ensure the piston and cylinder are correctly oriented. Place the cylinder on the bench. Hold the piston near the top, using the thumb and forefinger, and lower it slowly into the cylinder bore, see Figure 4. Release the piston as it starts to engage in the cylinder bore. It should then slide freely into the cylinder. Never apply force. If the piston sticks then take it apart and try again.

If the piston-cylinder unit performance does not improve after cleaning several times then it may require repair. Repair of a damaged piston-cylinder unit is a specialised process so send the instrument back to the manufacturer or contact MSL for further advice. Never use abrasive material on the piston-cylinder unit.

References

[1] MSL Technical Guide 13: *Pressure gauge calibration*.

Further Information

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

Prepared by Mark Fitzgerald, Chris Sutton and Darrin Jack, June 2007.

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