USER'S MANUAL

MODEL P7800

MODEL P7800

HYDRAULIC PRESSURE STANDARD

USER'S MANUAL

Manufactured by;

GE RUSKA

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RELEASE NUMBER	REVISION	DATE OF REVISION	DESCRIPTION
PMAN-139-1D01	A	04/01/04	Original release.

WARNING

PRESSURIZED VESSELS AND ASSOCIATED EQUIPMENT ARE POTENTIALLY DANGEROUS. THE APPARATUS DESCRIBED IN THIS MANUAL SHOULD BE OPERATED ONLY BY PERSONNEL TRAINED IN PROCEDURES THAT WILL ASSURE SAFETY TO THEMSELVES, TO OTHERS, AND TO THE EQUIPMENT.

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1.0 GENERAL INFORMATION

The P7000 is a primary standard for pressure measurement. Utilising the well-proven Piston/Gauge system, consisting of a vertically mounted precision lapped Piston and Cylinder Unit (PCU), accurately calibrated weight masses (FORCE) are loaded on the Piston (AREA) which rises freely within its Cylinder. These Weights balance the upward force created by the pressure within the system.

$$\text{PRESSURE} = \frac{\text{FORCE}}{\text{AREA}}$$

Each weight is marked with the pressure standards serial number and a sequential number.

The pressure balance and any associated instruments are pressurised and therefore potentially dangerous. The pressure standard must be operated by personnel suitably trained to ensure their safety and that of the equipment.

Do not exceed the pressure stated on the label of the pressure standard.

Ensure that there is no pressure in the system by opening valve (8) before dismantling any part of the pressure system.

To ensure the best accuracy is attained, the instrument should be used in a draught free, thermally stable room. The benching should be sufficiently rigid so that it does not deflect under the load of the weight masses. The room should not have excess personnel movement.

All corrections in Section 2 should be considered and applied where necessary.

A full suite of PC based software is available to carry out all necessary calculations,
see Section 12.

2.0 CORRECTIONS

As stated in Section 1:-

$$P = \frac{F}{A}$$

where

P = Pressure
F = Force
A = Area

Although by definition the pressure equation appears simple, to ensure accuracy when using the pressure standard the following effects must be considered:-

- Gravity
- Temperature
- Air density
- Head of fluid
- Piston and cylinder (PCU) deformation
- Piston float height
- Verticality
- Fluid buoyancy and loading
- Surface tension
- Thermal stability

The individual effect of each of the above are discussed throughout this section. Calculations for the above are covered in the next section.

2.1 Gravity

The downward force generated by the piston and weights is directly proportional to gravity. Gravity varies considerably with the latitude and altitude of the location. To ensure accuracy, gravity should be surveyed at the bench height to six significant figures.
To correct for gravity apply the following:-

$$F = M\,(Gl/Gs)$$

where

F = Downward force
M = Mass of the piston and weights
Gl = Gravity at location in cm/s^2
Gs = Standard gravity 980.665 cm/s^2

2.2 Temperature

The effective area of the piston cylinder unit (PCU) has been calibrated and the results reported at 20 °C. As the temperature varies, so will the effective area of the PCU. This change is directly dependent on the thermal coefficient of expansion for the piston and cylinder.
The temperature throughout the calibration should remain stable, within 1 °C per hour. The pressure standard and instrument under test should be in the calibration location for at least 4 hours, ideally 24 hours to thermally stabilise. The temperature of the PCU should be known to 0.25 °C. Correct for changes in the effective area as follows:-

$$A_T = A\,(1 + \lambda\,(T - 20))\,(Gl/Gs)$$

where

A_T = Effective area at temperature T
A = Effective area at 20 °C
λ = Combined thermal coefficient of expansion of the piston and cylinder
T = Temperature of the piston and cylinder unit

2.3 Air Density

Mass by definition is taken in a vacuum. When the weight masses are used (gauge mode), they are used in atmosphere and therefore air is displaced. The mass of the object will reduce by the amount equal to the mass of the fluid (air) displaced as per Archimedes principal. Therefore the downward force needs to be corrected for the air buoyancy effect as follows:-

$$Fc = F\,(1 - \rho a/\rho m)$$

where

Fc = Air buoyancy corrected force
F = Uncompensated force
ρa = Air density nominally 0.0012 g/cm^3 *
ρm = Mass density 8 g/cm^3

The mass values reported represent the mass of a hypothetical weight of density 8 g/cm^3 which would balance that weight in air of density 0.0012 g/cm^3 at 20 °C

* For air density values see Appendix A.

2.4 Head of Fluid

The pressure datum line is the top surface of the triangle. The height of the reference level of the instrument under test relative to this datum line should be corrected for due to the head of fluid as follows:-

$$H = h\;\rho f\,(1 - \rho a/\rho f)(Gl/Gs)$$

where

H = Head pressure
h = Vertical distance between the top face of the triangular base and the instrument under test
ρf = Density of the pressure medium
ρa = Air density
Gl = Gravity at location in cm/s^2
Gs = Standard gravity 980.665 cm/s^2

2.5 Piston and Cylinder (PCU) Deformation

As pressure is applied, both the piston and cylinder reversibly distort. This distortion alters the effective area of the PCU. The distortion is assumed to be linear and has been calculated by cross floating the PCU at various pressures across its operating range, and applying the best straight line fit (least square) to the results. Correct for the change in area with pressure as follows:-

$$A = A_o (1 + aP)$$

where

A = Effective area at pressure P
A_o = Effective area of the piston at zero pressure
a = Pressure deformation coefficient
P = Operating pressure

2.6 Piston Float Height

The piston and cylinder unit has been calibrated with reference to the bottom face of the piston at its mid operating position. Therefore during calibration at the point of taking the reading the piston should be at its mid operating position. Variation from the mid operating position will result in both a head of fluid error and the possibility of a slight change in the effective area due to the geometry of the piston. Therefore for the best result the piston should be spinning at its mid operating position at the time of taking the calibration reading.

2.7 Verticality

The piston must be vertical otherwise a proportion of the downward force acting on the piston will be transferred to the wall of the cylinder. The force is proportional to the cosine of the angle of the piston relative to the vertical, and can be corrected as follows:-

$$F_v = F \times \cos\theta$$

where

F_v = Corrected force
F = Vertical force
$\cos\theta$ = Angle between the piston axis and vertical

To avoid the above always ensure that the triangular base has been levelled so that the piston is vertical. Each foot has a locking nut to ensure that no changes occur during calibration.

2.8 Fluid Buoyancy and Loading

Where the part of the piston that is submerged in the operating medium deviates from its working area, then the volume of this deviation needs to be corrected for as follows:-

$$M_c = M - V\rho f (1 - \rho a/\rho f)$$

where

M_c = Mass compensated for fluid buoyancy and fluid loading effect
M = Mass of the piston and weights
V = The net volume difference
ρf = Density of the pressure medium
ρa = Air density

2.9 Surface Tension

The operating medium passes between the piston and cylinder to atmosphere. At the interface between the operating medium and atmosphere there is an additional downward force which is generated by the surface tension of the operating medium and is compensated for as follows:-

$$Fc = F + SC$$

where

Fc = Force compensated for surface tension
F = Downward force
S = Surface tension of the pressure medium
C = Circumference of the piston

2.10 Thermal Stability

The pressure system is a closed system. As the pressure is increased to float the piston, heat is generated. As this heat dissipates, the piston will fall more quickly. Therefore sufficient time, typically 5 minutes, must be allowed for the system to thermally stabilise. The time required will vary with the speed and magnitude of the pressure change. The effect is inverted for decreasing pressures.

3.0 CALCULATIONS

Section 2 outlined the major effects that influence the pressure of the pressure standard. The following section covers worked examples.

A full suite of PC based software has been supplied to carry out all the calculations.

All calculations should be made to at least six significant figures.

3.1 Pressure Calculation

Use software program S740.
Combining all the influences mentioned in Section 2, we get the following equation:

$$P = K\,\frac{(M+\Sigma M)(1-\rho a/\rho m)(Gl/GS)\mathrm{Cos}\theta - V\rho f\,(1-\rho a/\rho f)(Gl/GS)\mathrm{Cos}\theta + Sc}{A\,(1 + ap + \lambda\,(T - 20))} - h\rho f(1-\rho a/\rho f)(Gl/GS) + RP - F \qquad (1)$$

where

P = Pressure

K = Pressure unit conversion factor from Kgf/cm^2:

For:		
	Kgf/cm^2	1
	bar	0.980665
	psi	14.22334

ρa = Density ambient air, g/cm^3 x 10^{-3}

ρm = Density weights, piston and weight carrier, g/cm^3 x 10^{-3}

M = Mass of the piston and weight carrier, Kg

ΣM = Sum of the weight masses used, Kg

Gl = Local acceleration due to gravity, cm/s^2

GS = Standard gravity 980.665 cm/s^2

θ = Angle in degrees between piston axis and vertical. Level the instrument so this is zero.

V = Net buoyancy volume of the piston cm^3

ρf = Density of the pressure medium, g/cm^3 x 10^{-3}

S = Surface tension of the pressure medium, Kgf/cm x 10^{-6}

c = Circumference of the piston, cm

h = Vertical distance between the reference level and the instrument under test, cm. Heights above reference level positive, heights below negative.

RP = Reference pressure in Kgf/cm^2. Zero for gauge mode and as measured for absolute mode.

F = Friction in the downward movement of the piston. This is only theoretical, provided the piston and cylinder are clean and rotating freely this will tend to zero.

A = Effective area of the PCU at zero pressure, cm^2 at 20 $^{\circ}$C

a = Piston pressure deformation coefficient, per MPa

p = Nominal pressure, MPa

T = Temperature of the piston and cylinder unit, $^{\circ}$C

λ = Combined thermal coefficient of expansion of the piston and cylinder, ppm per $^{\circ}$C x 10^{-6}

We can simplify equation (1) as follows:-

$\cos\theta \cong 0$
$RP = 0$
$F \cong 0$

GA = Combined gravity and air density correction
$(1 - \rho a/\rho m)(Gl/GS)$

C = Buoyancy and surface tension constant
$V\rho f\,(1 - \rho a/\rho f)(Gl/GS) - Sc$

H = Head of fluid
$h\rho f\,(1 - \rho a/\rho f)(Gl/GS)$

The above can be treated as constants throughout the calibration. APT is pressure dependent and requires recalculating at each pressure point.

APT = Effective area at 20 $^{\circ}$C and pressure p
$A\,(1 + ap + \lambda\,(T - 20)$

therefore

$$P = K\,\frac{(M + \Sigma M)\,GA - C}{APT} - H \tag{2}$$

Calculate the pressure using equation (2)

Example A

$K = 0.980665$ (for bar)

$\rho a = 0.0012\ \text{g/cm}^3 \times 10^{-3}$

$\rho m = 8\text{g/cm}^3 \times 10^{-3}$

$M = 0.410946\ \text{Kg}$

$\Sigma M = 16.43603\ \text{Kg}$

$Gl = 981.196\ \text{cm/s}^2$

$GS = 980.665\ \text{cm/s}^2$

$V = 0.277\ \text{cm}^3$

$\rho f = 0.865\ \text{g/cm}^3 \times 10^{-3}$

$S = 30 \times 10^{-6}\ \text{Kgf/cm}$

$c = 1.006227\ \text{cm}$ (Calculated from area where $c = \Pi D$, Area $= \Pi D^2/4$)

$h = -2.4\ \text{cm} \times 10^{-3}$

$A = 0.0805716\ \text{cm}^2$

$a = 0.000002335$ per MPa

$p = 20.5\ \text{MPa}$

$T = 20\ ^{\circ}\text{C}$

$\lambda = 16.5 \times 10^{-6}$

therefore

$$\begin{aligned} GA &= (1 - 0.0012 \times 10^{-3}/8 \times 10^{-3})(981.196/980.665) \\ &= 1.00003914 \end{aligned}$$

$$\begin{aligned} C &= 0.277 \times 0.865 \times 10^{-3}\ (1 - 0.0012 \times 10^{-3}/0.865 \times 10^{-3})(981.196/980.665) - 30 \times 10^{-6} \times 1.006227 \\ &= 0.0002092 \end{aligned}$$

$$\begin{aligned} H &= -2.4 \times 0.865 \times 10^{-3}\ (1 - 0.0012 \times 10^{-3}/0.865 \times 10^{-3})(981.196/980.665) \\ &= -0.0020742 \end{aligned}$$

$$\begin{aligned} APT &= 0.0805716\ (1 - 2.335 \times 10^{-6} \times 20.5) \\ &= 0.080575 \end{aligned}$$

Using equation 2

$$\begin{aligned} \text{Pressure} &= 0.980665 \times \frac{(0.410946+16.43603) \times 1.0003914-0.0002092}{0.0805755}+0.0020742 \\ &= 205.1202\ \text{bar} \end{aligned}$$

3.2 Mass Calculation

Use software program S740 or S720 (as applicable).
To calculate the mass required to generate a specific pressure P, use equation (3).

$$\Sigma M = \frac{P \times APT + K \times (c + H \times APT)}{K \times GA} - M \qquad (3)$$

Example B

Using the same data as in example A we get, the mass required to generate a pressure of 205.1202 bar would be:

$$\Sigma M = \frac{205.1202 \times 0.0805755 + 0.980665(0.0002092 - 0.0020742 \times 0.0805755)}{0.980665 \times 1.0003914} - 0.410946$$

$$= 16.43603 \text{ Kg}$$

3.3 Area Calculation

Use software program S710.
To calculate the effective area of a piston and cylinder unit use equation (4).

$$A_T = \frac{(M_T + \Sigma M_T)GA - G_T}{(M_R + \Sigma M_R)GA - C_R - H \times APT} \times APT \qquad (4)$$

where

A_T = Effective area of the test piston and cylinder unit at pressure P.

M_T = Mass of the test piston and carrier, kg.

ΣM_T = Mass of the test weights, Kg

C_T = Buoyancy and surface tension of the test piston, Kg

H = Head of fluid, based upon the vertical distance between the bottom of the reference piston at its mid operating position and the bottom of the test piston at its mid operating position

M_R = Mass of the reference piston, Kg

ΣM_R = Mass of the reference weights, Kg

C_R = Buoyancy and surface tension of the reference piston, Kg

APT = Effective area of the reference piston at 20 $^{\circ}$C at pressure P

4.0 PISTON & WEIGHT DATA

4.1 PISTON DISPLACEMENT

PISTON	TOTAL DISPLACEMENT (mm)
PCU 26 (K426)	26.2
PCU 24 (K600)	18.6
PCU 25 (K610)	18.9
PCU 27 (K619)	10.8

4.2 NOMINAL PRESSURE GENERATED BY THE WEIGHTS

WEIGHT Nº	NOMINAL MASS g	NOMINAL PRESSURE (MPa)			
		PCU 26 K426	PCU 24 K600	PCU 25 & 27 K610	K619
1	8227	1	10	20	
2	8227	1	10	20	
3	8227	1	10	20	
4	8227	1	10	20	
5	8227	1	10	20	
6	8227	1	10	20	
7	8227	1	10	20	
8	8227	1	10	20	
9	8227	1	10	20	
10	8227	1	10	20	
11	8227	1	10	20	
12	8227	1	10	20	
13	8227	1	10	20	
14	4113	0.5	5	10	
15	2056	0.25	2.5	5	
16	411	0.05	0.5	1	
17	411	0.05	0.5	1	
18	411	0.05	0.5	1	
19	411	0.05	0.5	1	
20	206	0.025	0.25	0.5	
21	41	0.005	0.05	0.1	
22	41	0.005	0.05	0.1	
23	41	0.005	0.05	0.1	
23	41	0.005	0.05	0.1	
24	41	0.005	0.05	0.1	
CARRIER & DISH		0.2	1.9	3.8	3.7
MAXIMUM PRESSURE		7	70	140	280

5.0 SUPPLIED WITH THIS SYSTEM

P7800 Deadweight Tester system, comprising:

- 4 Piston Assemblies in various ranges
- Piston weight carrier and dish to load trim masses
- Calibrated weight set in wooden cases
- NPL Certificates of Piston Effective Area
- NAMAS Certificate of Weight Masses
- Pressure generation system assembly
  (Includes Ram Screw, Hand-pump, Reservoir, Test Port, etc)
- Levelling feet with locking nuts
- Foot locators
- Spirit level
- Operating Manual
- Piston Lubricating Oil - Specification: Our reference ST55
  Oil supplied - Shell Tellus 22
  Compatible oils - Esso Nuto H22
  - Mobil Velocite No.10

Auxiliary Plate Assembly comprising:

- Null Indicator with Isolation Valve
- High pressure (280 MPa) external connection port
- Low pressure (140 MPa) external connection port
- All necessary piping: Heavy small-bore Stainless Steel (Max. pressure 400 MPa)
  Light small-bore Stainless Steel (Max. pressure 140 MPa)
  Flexible hoses (Max. pressure 70 MPa)
- Various adaptors in both BSP and NPT for high and low pressure connection ports
- Spare Seals

Additional Equipment:

- Non-contacting piston displacement sensors & software
- Micrometer head
- Support stand
- S700M Software

6.0 SETTING UP

6.1 Setting Up From New

6.1.1 The pressure standard should be set up in a draught free, thermally stable room, free from excessive personnel movement.

6.1.2 The bench for the pressure standard should be sufficiently rigid to avoid deflection and be located on a stable floor.

6.1.3 Carefully unpack the instrument and associated components.

6.1.4 Place the Deadweight Tester on the bench, and Triangle (2) onto Foot Supports.

6.1.5 Connect pipe from left hand side of instrument to bottom of the column, do not over tighten.

6.1.6 Connect right hand side pipe to Valve (19) on Auxiliary Plate Assembly (18).

6.1.7 Fit Spokes to Hub (7) on the front of the Tester.

6.1.8 Level the triangular Base Plate using the three Adjustable Feet (4) to the Spirit Level (3) mounted in the Base Plate. Secure the Feet using knurled locking rings.

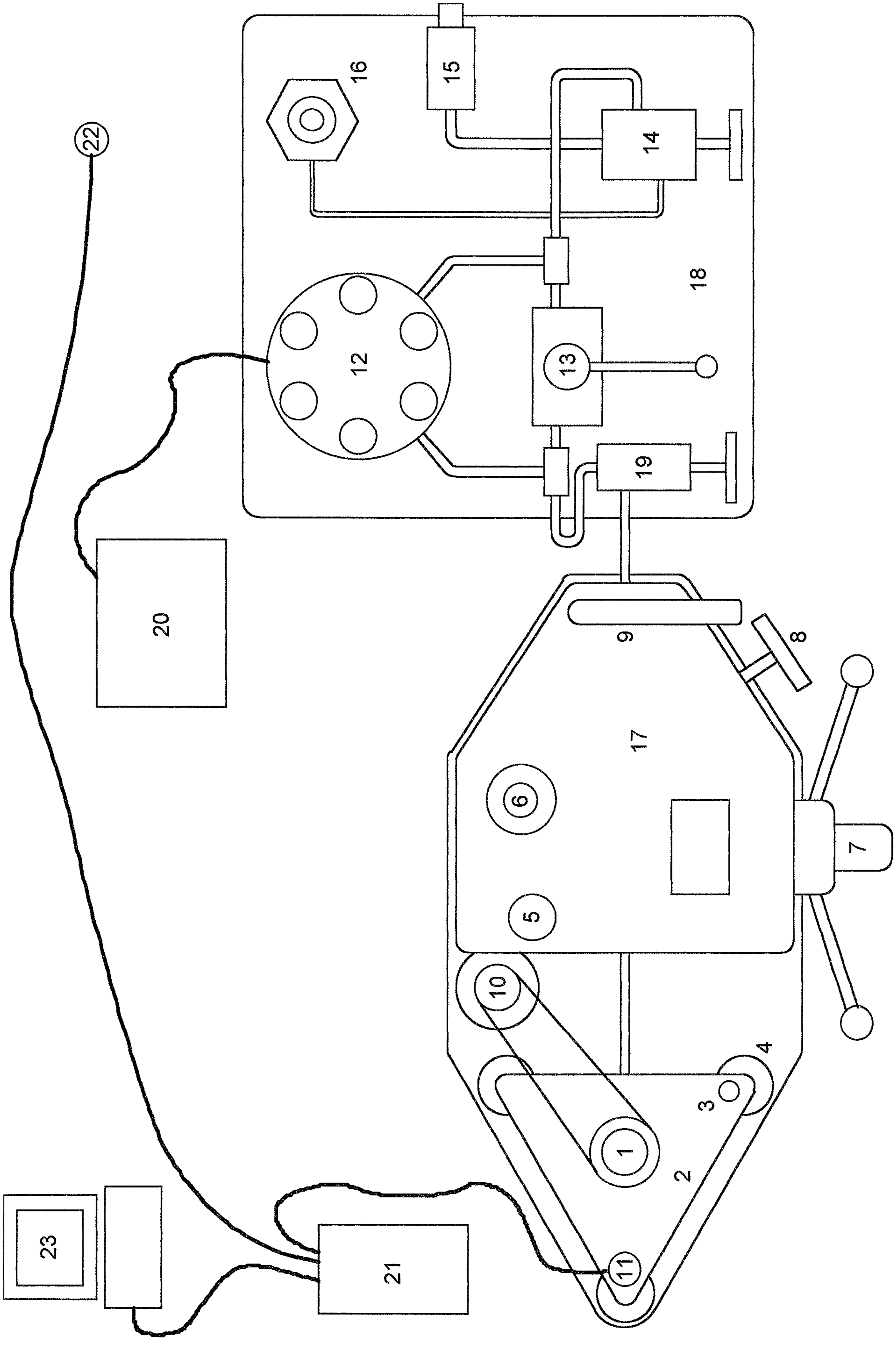
6.2 Electrical Connections

Please note that the Null Indicator, Motor Drive and Displacement Sensors are all set to a mains supply voltage of 110 Vac.

6.2.1 The Null indicator display is connected to the mains supply via standard mains lead. The display unit (20) is also connected to the Null pressure cell (12) via the special cable supplied.

6.2.2 The Displacement sensor control box is connected to the mains supply via the special transformer cable adaptor.
Each sensor has its own cable which must be connected to the control box.
The sensor (11) mounted in the triangular base is sensor 'A', and the remote, 'free' sensor is 'B'.
Ensure that the sensor cables are correctly connected to 'A' & 'B' respectively.
Care must be taken with the delicate contacts when connecting these cables, and tight bends or 'kinking' should be avoided to prevent internal damage to the cable.
An RS232 cable is supplied to connect the sensor control box to the COMM 1 port on the computer.

6.2.3 The power supply to the motor drive within the Deadweight Tester is connected via a standard mains lead to the rear face of the instrument.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ITEM	DESCRIPTION
1	PISTON ASSEMBLY
2	TRIANGULAR BASE ASSEMBLY
3	SPIRIT LEVEL
4	LEVELLING FOOT ASSEMBLY
5	RESERVOIR
6	DEADWEIGHT TESTER TEST PORT
7	CAPSTAN
8	RESERVOIR VALVE
9	HANDPUMP
10	MOTOR DRIVE ASSEMBLY
11	DISPLACEMENT SENSOR 'A'
12	NULL DISPLACEMENT SENSOR
13	BY-PASS VALVE
14	LOW PRESSURE SHUT-OFF VALVE
15	HIGH PRESSURE TEST PORT
16	LOW PRESSURE TEST PORT
17	REFERENCE DEADWEIGHT TESTER
18	AUXILLARY PLATE ASSEMBLY
19	SHUT-OFF VALVE
20	NULL INDICATOR
21	DISPLACEMENT SENSOR CONTROL BOX ASSEMBLY
22	DISPLACEMENT SENSOR 'B'
23	PERSONAL COMPUTER

6.3 Priming

IMPORTANT:
Close Valve (19) on Auxiliary Plate before attempting to prime Deadweight Tester.

Deadweight Tester:

6.3.1 Fill Reservoir (5) approximately 3/4 full with correct operating oil, and close Valve (8).
6.3.2 Slowly pump Handpump (9) until oil appears at top of column and at Test Station (6). Ensure a Lens Ring is fitted to the Test Station, then plug the Test Station using the Blanking Plug and 1/2 BSP adaptor.
Note: Screw the Adaptor fully onto the Blanking Plug.
Screw the assembly down ANTI-CLOCKWISE onto the Test Station,
(The internal thread in the lower half of the adaptor is LEFT-HANDED)
Ensure that the bottom face of the plug contacts the Lens Ring.
Tighten fully to ensure a good seal. (The lens ring may distort with use, replace as required.)
6.3.3 Select the correct piston assembly depending upon the pressure range required, see Section 4.
6.3.4 Mount piston assembly onto column, see Section 10.

Auxiliary Plate:

6.3.5 Open Valve (19), and close Valve (13)
6.3.6 Remove plug from underside of Null Pressure Cell (12), (place drain cup below to catch oil), pump handpump (9) slowly until oil runs into drain cup. Replace plug.
6.3.7 Open Valve (13).
6.3.8 Ensure that Valve (14) is closed.
6.3.9 Remove plug from HP Test Port and slowly pump Handpump (9) until oil appears from HP Test Port (15). Replace plug.
6.3.10 Remove plug from top of Null Pressure Cell (12), pump handpump (9) slowly until oil appears at top of thread. Replace plug.
6.3.11 Remove Blanking Adaptor from LP Test Port (16). Open Valve (14) and slowly pump Handpump (9) until oil appears at top of Low Pressure Test Port (16).
Replace Blanking Adaptor, ensuring that the 'O' Ring is correctly fitted and undamaged.

6.4 General

6.4.1 Open Valve (8) two turns anti-clockwise and screw Capstan (7) fully in.
6.4.2 Gently pump Handpump (9) twice.
6.4.3 Close Valve and screw Capstan FULLY OUT.
6.4.4 Open Valve and screw Capstan FULLY IN.
Note: During this operation bubbles may appear in the Reservoir (5), as trapped air is expelled. For large volume instruments repeat steps 6.4.3 & 6.4.5 until no further bubbles appear.
6.4.5 With Valve open, screw Capstan FULLY OUT and close Valve. The Tester is now ready for use.

7.0 PRESSURE MEASURED CALIBRATION

Use software programs S740 or S750.

Ensure the correct PCU is fitted, to cover the pressure range of the instrument to be tested, and Valve (13) is **OPEN**.

7.1 Fit instrument to be tested to the appropriate Test Port:

a) For devices up to 140 MPa with conventional thread fittings - use the Low Pressure Test Port (16).

b) For devices up to 280 MPa with conventional thread fittings - use the Test Port mounted directly on the Deadweight Tester (6).

c) For devices above 140 MPa, with non-conventional thread fittings - use the High Pressure Test Port (15) in conjuction with suitable piping and connectors.

a) Notes for Low Pressure Test Port:

It is advisable to use this port whenever possible to reduce the possibility of system contamination, as it is designed as a trap for particles that may fall from inside the device under test.
The top unscrews, allowing the operator to inspect and clean the chamber within.
This should be carried out on a regular basis, especially if any contamination is suspected.
(The Bulb Syringe supplied with this equipment is designed for this purpose).
This port is supplied with adaptors to accept 1/8, 1/4, 3/8 & 1/2 BSP and NPT male threads.

To use:
Screw the appropriate adaptor fully onto the instrument to be tested.
Screw assembly down ANTI-CLOCKWISE onto the Test Port.
The internal thread in the lower half of the adaptor is LEFT-HANDED.
Ensure that the bottom face of the instrument to be tested contacts the seal on the Test Port.
To adjust position to face forward - hold the adaptor and unscrew the instrument to be tested ANTI-CLOCKWISE so that it faces forward. Hold the instrument to be tested steady whilst turning the adaptor ANTI-CLOCKWISE until it pulls down onto the seal.
Tighten fully to ensure a good seal.

b) Notes for Deadweight Tester Test Port:

This port is supplied with adaptors to accept 1/2 & 3/4 BSP male threads, and is generally used for mounting high pressure devices directly onto the Deadweight Tester.
When using this port, close Valve (19).

c) Notes for High Pressure Test Port:

This port is supplied with piping and a range of adaptors to allow connection to a variety of systems.

7.2 It is important to ensure that the system is purged of trapped air.
Any device fitted to the test port should be internally clean, and filled with the correct oil.
Before fitting the device to the test port, use the Handpump (9) to gently pump fresh oil through the system until it reaches the sealing face of the test port.

7.3 Select the required weights and stack onto the Piston Weight Carrier (1).
The pressure measured is the sum of the weights plus the Piston Weight Carrier.
Use software program S750. If a specific pressure is required use software programS740.

7.4 The trim mass dish is included in the weight carrier mass, ensure that it is mounted on the top of the carrier tube when all readings are being taken.

Note: It is important to measure the difference in height between the bottom of the sealing face of the device under test and the Mid Operating Position of the piston assembly being used.
To assist in head corrections, the adaptor has a horizontal groove which nominally aligns to the bottom of the piston in its mid operating position. This reference groove is based on the standard dimension of a PCU.
Record the temperature of the PCU.
Both these parameters can be input into the software.

7.5 To generate pressure up to approximately 1 to 2 MPa, use Handpump (9), for highe pressures, screw the Capstan (7) in until the piston/weight carrier assembly is floating at the Mid Operating Position (MOP).
If there is insufficient volume in the capstan, close Valve (19), screw Capstan fully out, and pump Handpump (9).
Screw Capstan in until the weights float, then gently back-off until the piston is resting in the bottom position, then slowly open Valve (19).
Continue to pressurise the system using Capstan.

7.6 IMPORTANT: When increasing pressure, particularly large pressure increments, the heat built up within the system will take some time to dissipate.
This is generally observed as an increase in the piston fall-rate, and can be misinterpreted as a leak from the system.
Continue to gently turn the Capstan to compensate for the increased fall-rate.
The fall-rate will return to normal as the temperature stabilises.

7.7 **Note**: To establish the MOP of the piston, run the sensor software program on the PC, and select the appropriate display (Graphical [E Chart]; Bar Chart; Numerical).
With the piston at rest on its' bottom stop, note the 'park' position.
From Section 4.2, take the total travel figure for the piston fitted, and divide by two.
Add this to the 'park' figure to find the MOP.
For example:
If the sensor displays 0.203mm with the weight carrier fully down, and PCU 24 (K600) is fitted, then the MOP = (18.6 / 2) + 0.203 = 9.503mm.
If running the 'E Chart' display on the sensor software, then we would recommend using a Graph Offset of 10.

7.8 Rotate the weight stack clockwise.

Note: The reference piston is fitted with a motor drive to rotate the weights.
The drive is designed to turn at variable speeds during start-up and shut-down.
Pressing the Green button will start the drive slowly to reduce "pulsing" the system.
After a few revolutions the drive will accelerate to full operating speed.
Pressing the Red button will start the deceleration cycle by slowly reducing the drive speed until the weights come to rest.

During this process an indicator light will change colour showing which section of the cycle is currently in operation:

Orange:	Stand-by mode.	(No rotation).
Un-lit:	Acceleration Cycle.	Do not calibrate.
Green:	Stable rotation.	Calibrate now.
Red:	Deceleration Cycle.	Do not calibrate.
Orange:	Stand-by mode.	(No rotation).

7.9 Observe the reading of the instrument under test.

7.10 For the next higher calibration point, repeat 7.6 above.

7.11 To measure reducing pressures, remove the necessary weights, and screw the Capstan out so that the weight stack floats at the correct height, then rotate clockwise.

7.12 Depressurise by screwing Capstan FULLY OUT.
NEVER RELEASE SYSTEM PRESSURE WITHOUT SCREWING CAPSTAN FULLY OUT FIRST.

7.13 Remove any remaining weights.

8.0 DEADWEIGHT TESTER CALIBRATION

The Deadweight Tester can be calibrated by two methods:-

Method 1

The resultant pressure generated from the Deadweight Tester and weights is compared with the reference pressure. This is the method covered in Section 8.1.

The disadvantage of this method is that the calibration is simply qualifying that a specific weight or weight combination is measuring a specific pressure.

Method 2

This is a more fundamental calibration where the effective area of the test PCU and the individual weight masses of all the test weights are established.

This means any weight or weight combination can be accomodated.

However, in order to carry out this calibration there must be a facility for measuring mass.

Calibration by this method is covered in Section 8.2.

8.1 Pressure Measured calibration (Method 1)

Use software program S750.

8.1.1 Remove the PCU(s) from the Deadweight Tester to be calibrated. Clean the PCU(s) and check for magnetism, de-magnetise if required, and re-assemble.
Clean all the weight masses.

8.1.2 Ensure the Deadweight Tester to be calibrated (Dwt_{CAL}) is internally clean, (ideally: fully dismantle, clean and reassemble) filled with the correct fluid, free from leaks and fully purged of air.
Connect the Dwt_{CAL} directly to either the Low Pressure Test Port (16) or High Pressure Test Port (15), depending upon its maximum pressure range.
Ensure the connection pipe is fully primed with fluid to avoid any potential head errors, and the capstan on the Dwt_{CAL} is fully out.

8.1.3 Check the correct reference piston is fitted and that the trim mass dish is mounted on the carrier tube when all readings are being taken.

8.1.4 Measure the height difference between the reference pistons' mid-operating position groove, and the pressure datum on the Dwt_{CAL}.
This can be done using numerous techniques, such as using a straight edge with a spirit level, or a liquid column.
Use this height for input in software program S750.

8.1.5 Ensure Valve (13) is open.

8.1.6 Place the test weights for the first calibration point onto the test piston.
Record the test weights used. Add the reference weights to the reference piston which nominally correspond to the test pressure value.

8.1.7 Pressurise the system initially by Handpump (9).
Then either screw Capstan (7) in, or use the capstan on the Dwt_{CAL}.
Note: Capstan (7) is for high pressure generation, and therefore has limited displacement.
In the unlikely event of displacement at high pressure is insufficient using both capstans, see Section 7.5.
Pressurise the system until both pistons are floating at their mid operating positions.

Notes for establishing piston Mid Operating Positions:

Reference Piston

To establish the MOP of the reference piston, run the sensor software program on the PC, and select the appropriate display (Graphical [E-Chart]; Bar Chart; Numerical).
With the piston at rest on its' bottom stop, note the 'park' position.
From Section 4.2, take the total travel figure for the piston fitted, and divide by two.
Add this to the 'park' figure to find the MOP.
For example:
If the sensor displays 0.203mm with the weight carrier fully down, and PCU 24 (K600) is fitted, then the MOP = (18.6 / 2) + 0.203 = 9.503mm.
If running the 'E-Chart' display on the sensor software, then we recommend using a Graph Offset of 10.

Test Piston

To establish the MOP of the test piston, measure the position of the bottom face of the carrier ring when the piston is fully down. Pressurise by screwing in the capstan until the piston is against its top stop.
Again measure the carrier position.
The mid operating position of the piston will be half way between these two points.
Use the adjustable clamp frame to position the remote sensor 'B' under the weights.
Again, set the offset as described above.

8.1.9 Pressurise until both pistons are above their MOP, and rotate both sets of weights.

Note: The reference piston is fitted with a motor drive to rotate the weights.
The drive is designed to turn at variable speeds during start-up and shut-down.
Pressing the Green button will start the drive slowly to reduce "pulsing" the system.
After a few revolutions the drive will accelerate to full operating speed.
Pressing the Red button will start the deceleration cycle by slowly reducing the drive speed until the weights come to rest.

During this process an indicator light will change colour showing which section of the cycle is currently in operation:

Orange:	Stand-by mode.	(No rotation).
Un-lit:	Acceleration Cycle.	Do not calibrate.
Green:	Stable rotation.	Calibrate now.
Red:	Deceleration Cycle.	Do not calibrate.
Orange:	Stand-by mode.	(No rotation).

8.1.10 The reference piston should rise and the test piston fall. If this is not the case, reduce the weights on the reference piston by the smallest increment.
Add and subtract trim weights on the dish of the reference piston until both pistons are rotating and falling at their natural fall rates across their respective mid operating positions.

Note: The natural fall rate can be established at each pressure by closing Valve (19), floating each piston at its MOP, and viewing the displacement on the PC screen.

8.1.11 The Null Indicator is provided to assist in establishing equilibrium.
For full information, see Section 9.
Always ensure that the Shunt is on, use the left Zero pot to adjust, so the needle reads zero.
After a pressure change, allow 5 to 10 minutes to thermally stabilise.
Close Valve (13), add and subtract trim weights until the needle is within 1/2 division of zero.
Set the Gain to 10 and switch off the shunt.
Open Valve (13) and re-zero, close Valve (13) and trim until zero.
When there is no zero shift between Valve (13) being open or closed, equilibrium has been established.

8.1.12 Record the reference weights and trim weights used on the reference piston.
Record the temperature of both PCUs and calculate the pressure as stated in Section 3.1.
This is the true pressure to be compared to the nominal pressure from the test piston and weights.

8.1.13 For the next calibration point repeat from 8.1.5.

8.1.14 After all calibration points have been completed, unscrew the capstan fully out.
Open Valve (8), wait 5 seconds and close.

8.2 Effective Area & Mass Calibration (Method 2)

Use software program S710.

8.2.1 Remove the PCU(s) from the Deadweight Tester to be calibrated. Clean and weigh the PCU(s) and check for magnetism, de-magnetise if required. If the submerged part of the piston has a 'head' or stop, then calculate the net volume outside the piston operating area. Calculate the surface tension corrections.
Clean and weigh all the weight masses. Input mass values, heaviest first, into mass data file.

8.2.2 Ensure the Deadweight Tester to be calibrated (Dwt_{CAL}) is internally clean, (ideally: fully dismantle, clean and reassemble) filled with the correct fluid, free from leaks and fully purged of air.
Connect the Dwt_{CAL} directly to either the Low Pressure Test Port (16) or High Pressure Test Port (15), depending upon its maximum pressure range.
Ensure the connection pipe is fully primed with fluid to avoid any potential head errors, and the capstan on the Dwt_{CAL} is fully out.

8.2.3 Check the correct reference piston is fitted and that the trim mass dish is mounted on the carrier tube when all readings are being taken.

8.2.4 Measure the piston length and travel. Using this information relative to the sealing face of the cylinder, work out the distance of the bottom of the piston in its mid operating position from the sealing face.

8.2.5 Measure the height difference between the reference pistons' mid-operating position groove, and the test pistons' MOP.
This can be done using numerous techniques, such as using a straight edge with a spirit level, or a liquid column.
Use this height for input in software program S750.

8.2.6 Ensure Valve (13) is open.

8.2.7 Place the test weights for the first calibration point onto the test piston.
Record the weights used. Add the reference weights to the reference piston, which nominally correspond in pressure terms, to the test weights.

8.2.8 Pressurise the system initially by Handpump (9).
Then either screw Capstan (7) in, or use the capstan on the Dwt_{CAL}.
Note: Capstan (7) is for high pressure generation, and therefore has limited displacement.
In the unlikely event of displacement at high pressure is insufficient using both capstans, see Section 7.5.
Pressurise the system until both pistons are floating at their mid operating positions.

Notes for establishing piston Mid Operating Positions:

Reference Piston
To establish the MOP of the reference piston, run the sensor software program on the PC, and select the appropriate display (Graphical [E-Chart]; Bar Chart; Numerical).
With the piston at rest on its' bottom stop, note the 'park' position.
From Section 4.2, take the total travel figure for the piston fitted, and divide by two.
Add this to the 'park' figure to find the MOP.
For example:
If the sensor displays 0.203mm with the weight carrier fully down, and PCU 24 (K600) is fitted, then the MOP = (18.6 / 2) + 0.203 = 9.503mm.
If running the 'E-Chart' display on the sensor software, then we recommend using a Graph Offset of 10.

Test Piston
To establish the MOP of the test piston, measure the position of the bottom face of the carrier ring when the piston is fully down. Pressurise by screwing in the capstan until the piston is against its top stop.
Again measure the carrier position.
The mid operating position of the piston will be half way between these two points.
Use the adjustable clamp frame to position the remote sensor 'B' under the weights.
Again, set the offset as described above.

8.2.9 Pressurise until both pistons are above their MOP, and rotate both sets of weights.

Note: The reference piston is fitted with a motor drive to rotate the weights.
The drive is designed to turn at variable speeds during start-up and shut-down.
Pressing the Green button will start the drive slowly to reduce "pulsing" the system.
After a few revolutions the drive will accelerate to full operating speed.
Pressing the Red button will start the deceleration cycle by slowly reducing the drive speed until the weights come to rest.

During this process an indicator light will change colour showing which section of the cycle is currently in operation:

Orange:	Stand-by mode.	(No rotation).
Un-lit:	Acceleration Cycle.	Do not calibrate.
Green:	Stable rotation.	Calibrate now.
Red:	Deceleration Cycle.	Do not calibrate.
Orange:	Stand-by mode.	(No rotation).

8.2.10 The reference piston should rise and the test piston fall. If this is not the case, reduce the weights on the reference piston by the smallest increment.
Add and subtract trim weights on the dish of the reference piston until both pistons are rotating and falling at their natural fall rates across their respective mid operating positions.

Note: The natural fall rate can be established at each pressure by closing Valve (19), floating each piston at its MOP, and viewing the displacement on the PC screen.

8.2.11 The Null Indicator is provided to assist in establishing equilibrium.
For full information, see Section 9.
Always ensure that the Shunt is on, use the left Zero pot to adjust, so the needle reads zero.
After a pressure change, allow 5 to 10 minutes to thermally stabilise.
Close Valve (13), add and subtract trim weights until the needle is within 1/2 division of zero.
Set the Gain to 10 and switch off the shunt.
Open Valve (13) and re-zero, close Valve (13) and trim until zero.
When there is no zero shift between Valve (13) being open or closed, equilibrium has been established.

8.2.12 Record the reference weights and trim weights used on the reference piston.
Record the temperature of both PCUs and calculate the pressure as stated in Section 3.
This is the effective area of the test piston, at that pressure.

Note: The test piston and weights may have a head correction from the bottom of the piston in its mid operating position to the test station seal in the Deadweight Tester base. This head correction may need to be taken into account when comparing results. Similarly, if the Deadweight Tester is manufactured for a different gravity, then this must be taken into account.

8.2.13 For the next calibration point repeat from 8.2.7.

8.2.14 With the effective area results at different pressures, you can apply least square fit to the results to attain the change in area as a function of pressure (pressure deformation coefficient, a), and the effective area of the piston at zero pressure (Ao).

9.0 Ruska Differential Pressure Null Detector

General Description

The Differential Pressure Null Detector, composed of a Differential Pressure Transducer (2417) and Electronic Null Indicator (2416), is designed to sense small pressure differences in both low and high pressure systems.

The transducer consists of two pressure chambers, separated by a thin diaphragm.
A difference in pressure in the two chambers causes a deflection of the diaphragm and a resultant signal to the electronic circuit.
The signal is obtained as the output of a differential transformer whose movable core is attached to the diaphragm.
The signal is not a linear function of the difference in pressure; therefore, use of the instrument for accurate evaluation of pressure differences is limited to small deflections of the diaphragm.
The principle use of the instrument is intended as a null sensor/indicator with which the pressure of one medium may be precisely adjusted to that of another.
Some of the advantages of the instrument are its high sensitivity, high working pressure (40000 PSI for 2417 Series cells), and its ability to withstand full working pressure across the diaphragm without injury.
(15000 PSI maximum over-range pressure both series).

Specifications

Inaccuracy:

Inaccuracy is defined as the error in the null indication.
It is expressed as the ratio of ΔP actually existing when the meter indicates a null, to the total cell pressure, in parts per million, or as a constant ΔP -- whichever is the greater.

	PPM	ΔP PSI
Error with calibration corrections	5	0.01
Error without calibration corrections	20	0.1

Sensitivity:

The sensitivity is continuously variable from 2×10^{-4} PSI ΔP per meter division to 0.01 PSI ΔP per meter division.
The maximum value may exceed 2×10^{-4} PSI/division because of variations in diaphragm characteristics and circuit parameters.

Operating Pressure:

40000 PSI for 2417 Series cells (see pressure media for limitations).

Static Test Pressure:

22000 PSI for five minutes with nitrogen.
The ungasketed metal seals act as relief valves when pressures exceed 22000 PSI.
The bolts yield to the increased load and permit the excess pressure to escape.
All attempts at destructive testing of these units have failed.
50000 PSI for 2417 Series cells.

Over-Range Pressure:

15000 PSI ΔP either side of diaphragm for 2417.

Construction Material:

Basic material of the transducer is one of the 400 series stainless steels.

Pressure Media:

Lower Chamber of pressure cell -- Dry air, nitrogen, mercury, or any fluid inert to 400 or 300 Series Stainless Steels.

Upper Chamber -- Dry air, nitrogen, or any fluid inert to 400 or 300 Series Steels, low-carbon iron, brass, copper, PVC, cadmium-plated steel, or soft solder. Electrolytes may not be used in the upper chamber.

It is not recommended to use fluids in either cavity containing free hydrogen. The use of such fluids is hazardous because of possible hydrogen embrittlement of the cell body. (Consult the manufacturer for cells of special materials).

Temperature Range:

40 ^{o}F to 160 ^{o}F.

Construction Details and Parameters

(Values shown under this heading are nominal at time of this publication and are not to be considered as binding specifications. They are subject to change with improvements in design and technology.)

Change in Null with Working Pressure — See Specifications

The stress from the applied pressure produces a displacement of the core within the transformer even though the pressure across the diaphragm may be zero. The displacement results in a shift of the apparent null with the true null and is approximately a linear function of the pressure. A calibration curve is supplied with each instrument to indicate the magnitude of the null shift.

Change in Null with Over-Range Pressure — < 0.05 PSI

The null change with over-range pressure arises from dimensional variations within the cell body. The value shown represents the maximum expected change when the cell is over-ranged from alternate sides of the diaphragm. In practice, a procedure is used that permits intentional over-ranging from only one side. After several such applications of over-range pressure from the same side, null indication becomes stable. If the cell is accidentally over-ranged from the opposite side, there is no harm except for a temporary loss of the original null setting. The cell must then be over-ranged from the original side to re-establish the true null.

Approximate Range of ΔP:

± 2 PSI

Volumes of Cavities:

Upper -- 29.5 cc

Lower -- 0.6 cc

Effective Diameter of Diaphragm:

1.9 inches

Thickness of Diaphragm:

0.002 inch

Types of Fittings:

For 2417 Series, NBS threaded cone fittings.

RUSKA Differential Pressure Null Indicator

Applications

The Model 2416 may be employed as a null detector / indicator in the following manner:

The Differential Pressure Transducer may be employed as a null detector between two liquid systems. For instance, when calibrating elastic sensors prepared for oxygen service, it is sometimes more convenient to use a liquid pressure medium than to use a gas. The liquid medium, of course, must be chemically inactive in the presence of oxygen in all concentrations. Mixtures of the volatile fluorocarbon solvents are frequently used for this purpose. The system containing the fluorocarbon may be balanced against the oil deadweight gauge system to pressures as high as 40,000 psi.

A special application of the differential pressure null indicator is one in which the unit is used when cross-floating two deadweight gauges. A by-pass valve arrangement is provided for the purpose of directly connecting the two gauges while making preliminary balancing adjustments. When the two gauges are at pressure and approximately balanced, the valve is opened and the electrical zero adjusted. The valve is then closed the balancing operation continued, while observing the residual pressure difference on the meter. As the pressures become more nearly equal, the valve is opened to verify the correct zero adjustment and then closed and opened alternately until no difference in meter readings is observed when the valve is either open or closed. The resolution of the entire system is quickly determined by placing a small weight on one gauge and observing the effect on the meter. When using the transducer for this purpose, calibration of the null shift working pressure is unnecessary.

Preparation For Use

Normally, when a transducer is shipped from the factory, it has been calibrated with nitrogen and is dry in both cavities. Before installation, a quick performance test may be made by first connecting the box to the cell, with power on, adjusting the sensitivity to maximum and the meter to zero. By pressing against the end of the open fittings with the finger, the meter will be seen to deflect. The effect will be less when pressing on the upper fitting, since the upper cavity has a volume some fifty times greater that the lower cavity. At maximum sensitivity, it should be relatively easy to deflect the meter from zero to full scale when pressing on the lower fitting.

All fluids should be filtered before their introduction into the pressure system. A small, hard particle, such as a metal chip, in a diaphragm cavity will perforate the diaphragm when the cell is over-ranged. Every effort should be made to keep contaminating particles out of the transducer.

In charging the upper cavity with a liquid, it is important to displace most of the air with the liquid. There are many traps in the cavity which may retain small air bubbles. If these bubbles remain in contact with the diaphragm or stem which carries the transformer core, the performance will be erratic. The fact that the air bubbles dissolve in the liquid when the pressure is increased may be used to an advantage. With the vent plug removed, the liquid is pumped into the upper chamber until it appears at the vent port. The plug is replaced and the pumping continued until the pressure in the liquid system reaches 150 atm or so. At this pressure, the entrapped bubbles dissolve in the liquid, forming a concentrated solution in the vicinity of the trap. Some time should be allowed for the solution to diffuse so that, when the pressure is released, the bubbles will not reappear in the same trap. The bubbles must reappear at some new point where they may rise to the top of the chamber and be expelled through the vent port. The presence of a bubble in the top of the cell cavity does not affect the measurement significantly, but it does affect the response. It is therefore convenient to work the air out of the cavity as much as is practical.

The cavity may also be charged by first evacuating and then admitting the liquid to the evacuated chamber. Usually, some small bubbles still remain because of the difficulty in reducing the internal pressure sufficiently through the small-bore tubing.

The presence of remaining air in the cavity may be measured if the liquid pressure generator is a screw-type displacement pump and the system contains a bourdon-tube reference gauge. It is first necessary to measure the air that exists in the portion of the liquid system other than the transducer. To make this measurement, it is necessary to isolate the liquid system from the cell and the deadweight gauge (if one is used). If there is no valve on the line to the cell, the line must be temporarily disconnected and stopped off. The valve to the liquid supply reservoir is opened and the plunger advanced somewhat to remove the backlash in the pump spindle nut. With the reservoir valve closed, the screw crank is slowly rotated until the bourdon gauge pointer is observed to move a perceptible amount. The quantity of motion of the screw is noted. The motion of the crank should be small -- something like one-quarter turn or less. After re-attaching the differential transducer to the system and pressurising the opposite cavity to several hundred psi, the experiment with the screw pump is repeated. The difference in rotation of the screw crank in the two experiments represents the quantity of air remaining in the cell. In these experiments, the gauge pointer must not be resting against a pin at zero pressure. It is obvious that pressurising the opposite cavity will prevent the flexible diaphragm from spoiling the experiment. It is not difficult to keep the free air in the differential pressure transducer below 0.05 cc.

Bleeding Lower Chamber In A Liquid-To-Liquid System

When charging the small cavity beneath the diaphragm, a bias pressure is placed in the upper cavity to force the diaphragm against the lower cavity surface. After the plug beneath the cell is loosened, some liquid is forced into the lower fitting until the liquid appears around the plug threads. This method is adequate in most instances. A small bubble is trapped in the vertical section of the input port to the lower cavity; but after pressurising the liquid for a period and repeating the process, the bubble is mostly displaced or dissolved. For more thorough displacement of the air, the cell should be inverted.

Operating Instructions

In comparing the pressure of one system to that of another, it must first be established that the comparator or indicating device is adjusted correctly. The adjustment must assure the operator that all hydraulic and pneumatic heads have been accounted.

With the transducer connected between two systems and prepared for operation, the power is turned on and the circuit allowed to warm up for ten minutes. A sequence of operations must be adopted in which one of the systems is always at a higher pressure than the other during the period of change from one pressure to another. If there is a choice, it is of some advantage, in a liquid-to-gas system, to maintain the higher pressure in the liquid system during the period of change. This procedure is not difficult to execute for both increasing and decreasing changes in pressures. If it is intended to raise both systems pressures from one level to a higher one, the liquid pressure is raised first to a value somewhat below the final one. The diaphragm of the differential pressure cell is driven to the lower cavity surface where it supports the excess liquid pressure. The operator is then free to concentrate on raising the gas pressure to, but not in excess of, the liquid pressure. As the final pressure is approached, it is usually possible to raise both systems simultaneously, while keeping them sufficiently balanced for the meter pointer to remain on scale.

Before starting a measurement on a liquid-to-gas system, the differential pressure transducer is intentionally over-ranged in the direction proposed by the adopted procedure; i.e., from the liquid side. The pressure is allowed to remain for a minute or so and then released. In some manner, the liquid system must be opened to atmosphere at a point level with the diaphragm. An open-tube manometer consisting of a valve with an attached glass tube serves the purpose well. With the manometer valve opened and the gas system also opened to atmosphere, the liquid is adjusted to stand in the tube at the height of the diaphragm. Under these conditions, the pressure across the diaphragm is zero. The electrical circuit, with sensitivity set at maximum or whatever value has been chosen, may then be adjusted for the meter to indicate zero ΔP.

As the manometer valve is closed, the pumping action of the stem causes the liquid to rise slightly in the tube and the meter pointer to deflect. The deflection is a normal one which results from the disturbance of the liquid in the tube.

Before the measurement is begun, the sensitivity is reduced by placing the shunt switch on the ON position. The shunt switch reduces the gain of the circuit by a factor of approximately 1000. First, the liquid pressure and then the gas pressure becomes approximately equal to that of the liquid, it will be observed that the two pressures will rise simultaneously as the increase in gas pressure is continued. At this time, the diaphragm is being forced away from the lower cavity surface by the gas. The displacement of the diaphragm increases the pressure in the liquid system. Although the two pressures are approximately equal, a signal will not appear on the meter until the gas pressure is within 2 psi of the liquid, since this figure is the limiting value of the indicated differential pressure. Some liquid must be withdrawn from the differential pressure cell, allowing the diaphragm to move towards the centre of the cavity whereupon the meter signal will approach the zero. If a dead weight gauge is connected in the system, the pressure in the liquid may build up high enough to float the weights. With a slight excess of gas pressure, the diaphragm will then move freely across the cavity; the weights will be seen to rise rapidly. After the sensitivity is increased, by placing the shunt switch in the OFF position, the two pressures may be brought to a satisfactory balance.

The increase in pressure of the two fluids is accompanied by an increase in temperature. As the fluids give up their excess heat to the apparatus, each suffers a reduction in energy. While the piston gauge is floating, however, it acts as a regulator and holds the pressure of the liquid approximately constant. The shrinkage of the liquid from its loss in heat is reflected as an increase in the normal sink rate of the piston. The gas, being confined to a single-ended system, suffers a loss in pressure as it gives up its excess heat. The net effect is an unstable condition in which the indicator will signal a continuous reduction in the gas pressure as though the system was leaking. For rather large changes in the pressure level, the balance indication will approach a high state of excitement for the first minute or so. Complete stabilisation will require a period of up to one hour but, for calibration purposes, manual control of the gas will be possible after only a few minutes.

In reducing the pressure, the procedure is reversed. The gas pressure is first reduced and then followed by the liquid pressure.

At the conclusion of the measurement, some time must be allowed for a transducer to recover before the zero-pressure conditions are verified. Particularly, if the last reduction in pressure is of one or more thousand psi, the recovery period may be as much as 5 to 10 minutes.
A considerable quantity of heat is exchanged in the reduction process.

The procedure for operating a liquid-to-liquid system is much the same as described above, except that a second manometer is required in the second liquid portion of the system. When adjusting the differential pressure unit at the beginning of the test, both manometers must be opened to atmosphere and each liquid adjusted to the height of the diaphragm. It must be remembered that the density of the one liquid is often different from that of the other; the total head correction must consider the two densities with their interface at the diaphragm.

Some Observations Concerning The Performance Of Model 2416 Differential Pressure Unit

Actual Sensitivity Versus Apparent Sensitivity

Although the differential pressure indicator is regarded as a null-indicating instrument, the degree to which a true null may be achieved depends upon the readability of the error signal displayed on the meter. In order to obtain a readable error signal, the diaphragm must move.
The sensitivity of the instrument is expressed as the change in pressure divided by the corresponding change in meter reading -- the change in meter reading being a function of the motion or displacement of the diaphragm. The sensitivity must be determined in such a way that the tension in the diaphragm, resulting from the applied pressure, is the only restoring force which re-establishes equilibrium.

When one side of the diaphragm is opened to atmosphere and a small increment of pressure is applied to the other side, the diaphragm will move under the influence of the applied pressure. The motion will continue until the forces tending to move the diaphragm are equally opposed by the forces of tension in the diaphragm tending to resist the motion. The sensitivity is then equal to ΔP divided by the change in meter reading.

When one side of the diaphragm is connected to a single-ended system containing a gas under pressure, the circumstances are different. The forces of an applied pressure increment tend to move the diaphragm as before, but the forces resisting the motion are greater than before. As the diaphragm moves, the volume of the single-ended system is reduced and its pressure increased. The ΔP that was applied to the diaphragm is automatically diminished and the instrument sensitivity appears to be less than before.

An example of the extreme case is one in which the single-ended system is completely filled with a non-compressible liquid. As the pressure is increased on the opposite side of the diaphragm, the liquid will not permit the diaphragm to move. In this instance, the sensitivity will appear to be very poor, but the actual sensitivity is no different than when measured under ideal conditions.

Calibration

The calibration procedure consists of determining the pressure coefficient of the transducer, the maximum sensitivity, and the zero shift that accompanies alternate over-ranging pressures on the diaphragm.

The pressure coefficient is usually small -- on an average, being less than 10^{-5}/psi. When the transducer is used in a bi-fluid system, for the calibration of elastic pressure-measuring devices, the error of the transducer can often be disregarded. When used in an apparatus for basic PVT studies, the coefficient is significant and its expression is of more value if reported in units of diaphragm displacement per unit of pressure level rather than as a change in pressure differential per unit of pressure level. For very small samples, the displacement of the diaphragm can result in an intolerable change in the sample volume, and the error will not be corrected by an adjustment of the pressure in the amount indicated by a pressure correction curve. A calibrating procedure in which the diaphragm presumably can be restored to its isostatic position by a physical adjustment of the electrical sensing-indicating circuit has been adopted. The procedure involves simultaneous pressurisation of both sections of the transducer from a common source and measuring the correction required to maintain a null indication throughout a range of pressures.

The correction is applied as a change in the ten-turn zero adjusting potentiometer, the shaft of which is equipped with a turn-counting graduated dial. In practice, the dial knob is set near one end of its range and the transformer of the pressure cell adjusted to indicate an approximate null when the diaphragm is exposed to atmospheric pressure on each side. At each pressure level of operation, the dial is changed by an amount obtained from the calibration curve. The curve is plotted as the change in dial units as a function of operating pressure. Usually, it is necessary to decrease the dial registration as the pressure is increased.

The advantage of maintaining a more uniform volume of the sample by accepting the method of calibration just described outweighs the convenience of correcting the data by a computer adjustment of the errors in pressure resulting from the strain in the transducer. Manual adjustment of the potentiometer becomes a part of each measurement and must not be overlooked.

Detecting Leaks

The differential pressure unit may be used to indicate a change in pressure of one system with respect to that of another. The change may result from a leak or from a change in temperature. When the instrument is used for detecting leaks in a system, sufficient time must be allowed to eliminate temperature effects. Also, a leak in a liquid system will have a different rate indication than a leak of the same magnitude in a gas system. Some caution must be exercised when interpreting the results of this type of test.

10.0 PISTON CARE

The Piston and Cylinder Assembly is the most critical and sensitive part of the Tester. To maintain accuracy, the Piston must always slide freely in the Cylinder

Note: Ensure system is depressurised before attempting Piston removal, by turning Capstan fully out, then SLOWLY opening Valve (8).

10.1 Piston Removal - PCU 26

10.1.1 Remove Weight Carrier assembly.

10.1.2 Unscrew Cylinder (21), and carefully lift out Piston assembly.
If Cylinder nut is tight, a locating hole is provided in the side for insertion of a 'C' Spanner.

10.1.3 Remove Piston Cap (22) by lifting Piston and then sharply tapping down onto top of Cylinder.

10.1.4 Withdraw Piston from Cylinder.

10.2 Piston Removal - PCU 24 & 25

10.2.1 Remove Weight Carrier assembly.

10.2.2 Unscrew Sleeve Nut (31), and carefully lift out Piston assembly.
If nut is tight, a locating hole is provided in the side for insertion of a 'C' Spanner.

10.2.3 Gently pull Piston Cap (28) from Piston (26).
Do not pull in such a way as to bend the piston.

10.2.4 Withdraw the Piston / Cylinder assembly from the Sleeve Nut.

10.2.5 Withdraw Piston from Cylinder (27).

10.3 Piston Removal - PCU 27

10.3.1 Remove Weight Carrier assembly.

10.3.2 Unscrew Piston Nut B (38), and carefully lift out Piston Assembly (33).
If Nut is tight, a locating hole is provided in the side for insertion of a 'C' Spanner.

10.3.3 Unscrew Piston Nut A (37), taking care not to allow the Cylinder (34) to fall.
If Nut is tight, a 'C' Spanner can be used in the Oil Bleed Hole.

10.3.4 Separate Cylinder and Piston Nut A.

10.4 Piston Cleaning - All Types

10.4.1 Use 'non-fluffing', non-abrasive, lint-free tissue or absorbent cloth. Hold the Piston Assembly by the larger, 'Head' end, and rub the tissue back and forth along its length.

10.4.2 To remove all traces of contamination, the Piston must be immersed in a non-filming solvent such as Trichloroethylene or Isopropanol.

10.4.3 Using a NEW tissue, clean the Piston as before, pressing hard between thumb and forefinger along the Piston's length.

10.4.4 Place Piston carefully on a NEW tissue where it will not become dirty or damaged whilst the Cylinder is cleaned.
IMPORTANT: NEVER TOUCH THE WORKING AREA OF A CLEAN PISTON WITH BARE FINGERS - THE NATURAL OIL IN YOUR SKIN CAN CAUSE THE PISTON AND CYLINDER ASSEMBLY TO STICK

10.5 Cylinder Cleaning - All Types

10.5.1 Wipe excess fluid from the outside surfaces of the Cylinder.
10.5.2 Roll a tissue into a tapered rod of appropriate size. Force the tissue through the Cylinder bore by rotating. Ensure the tissue is tight so that dirt is removed. Repeat, inserting a NEW tissue from the opposite end
10.5.3 To remove all traces of contamination the Cylinder must be immersed in a suitable solvent.
10.5.4 After removal from the solvent, using a NEW tissue, repeat the cleaning process in 10.5.2

10.6 Piston Re-Assembly - General

The Piston must be carefully introduced into its Cylinder.
If both parts are aligned and correctly cleaned, the Piston will slide freely into the Cylinder.
NEVER FORCE THE PISTON INTO ITS CYLINDER OR DAMAGE MAY RESULT.
If resistance is felt, then re-clean either Piston, Cylinder or both.
If, after repeated cleaning, the Piston will not slide freely within the Cylinder, then permanent damage may have occurred, in which case the complete assembly will need to be replaced or returned for evaluation.

10.7 Piston Re-Assembly - PCU 26

10.7.1 Hold Piston by larger, 'head' end, dip the other end into a container of clean operating oil, and transfer to the bore in the threaded end of the Cylinder.
10.7.2 Allow the oil to run through the bore.
10.7.3 Repeat this procedure 2 or 3 times to ensure an even film of clean fluid exists within the bore.
10.7.4 Carefully introduce the Piston into the threaded end of the Cylinder, and push gently through.
10.7.5 Screw Piston / Cylinder assembly into Adaptor (23), ensuring that the Bonded Seal (24) is clean, undamaged and correctly fitted.
10.7.6 Replace Piston Cap (22), ensuring that the internal bore is clean.
10.7.7 Replace Weight Carrier assembly, ensuring that it locates correctly on the top of the Piston Cap

10.8 Piston Re-Assembly - PCU 24 & 25

10.8.1 Ensure that 'O' Ring (29) is correctly re-fitted into counter-bore in Cylinder.
10.8.2 Hold Piston by larger, 'head' end, dip the other end into a container of clean operating oil, and transfer to the bore in the underside of the Cylinder (27).
10.8.3 Allow the oil to run through the bore.
10.8.4 Repeat this procedure 2 or 3 times to ensure an even film of clean fluid exists within the bore.
10.8.5 Carefully introduce the Piston into the larger diameter end of the Cylinder, and push gently through.
10.8.6 Insert Piston / Cylinder assembly into Sleeve Nut (31), and screw down onto Adaptor (32), ensuring that the Bonded Seal (30) is clean, undamaged and correctly fitted.
10.8.7 Replace Piston Cap (28), ensuring that the internal bore is clean.
10.8.8 Replace Weight Carrier assembly, ensuring that it locates correctly on the top of the Piston Cap

10.9 Piston Re-Assembly - PCU 27

10.9.1 Place Cylinder (34) on top of Adaptor (40) with the register upwards, ensuring that the 'O' Ring (25) is clean and undamaged.

10.9.2 Replace Piston Nut A (37), and screw down securely.

10.9.3 Ensure that Bearing Assembly (39) and Thrust Washers are located correctly.

10.9.4 Close Valve (8), and gently use the Priming Pump (9) to raise the oil level in the system until it reaches the top of the Cylinder.

10.9.5 Holding the Piston Assembly by the Piston Cap (33), carefully introduce the end of the Piston into the top of the Cylinder and push gently through.

10.9.6 Replace Piston Nut B (38) and screw down securely.

10.9.7 Replace Weight Carrier Assembly, ensuring that it locates correctly on the top of the Piston Cap

10.10 Piston Spin / Sensitivity

IF PISTON IS NOT FREE, DO NOT ROTATE AS DAMAGE MAY OCCUR, DISMANTLE AND CLEAN.

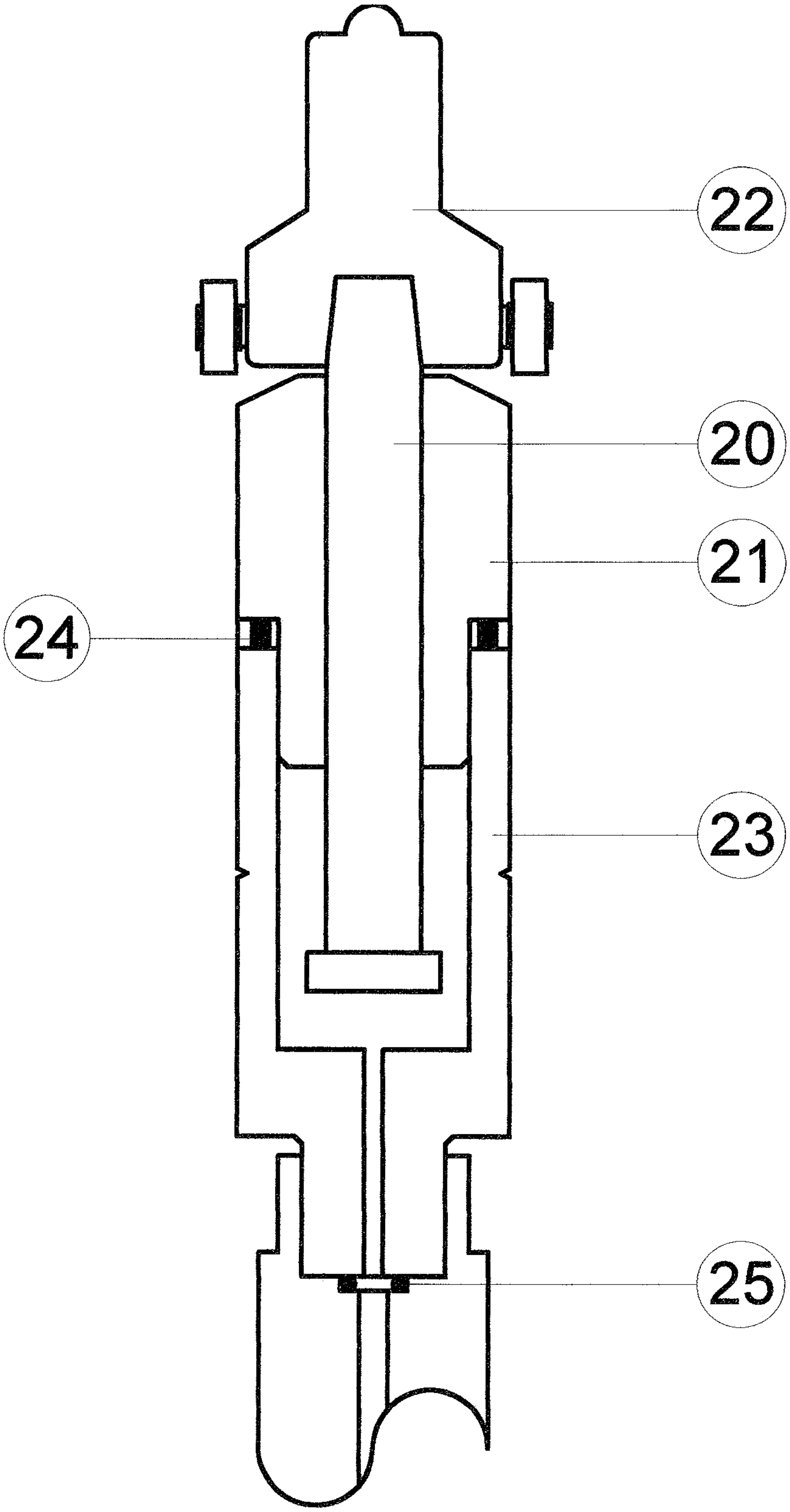
When floating the Piston and Weight Carrier alone, it should rotate freely, and slowly come to a smooth halt. If the rotation halts abruptly, then clean the Piston as described above.

Open Reservoir Valve. Lift off Weight Carrier Assembly. Holding the Piston cap, lift gently up and down. The Piston should slide freely within its Cylinder, if any resistance or a 'gritty' sensation is detected, then it must be cleaned as described above.

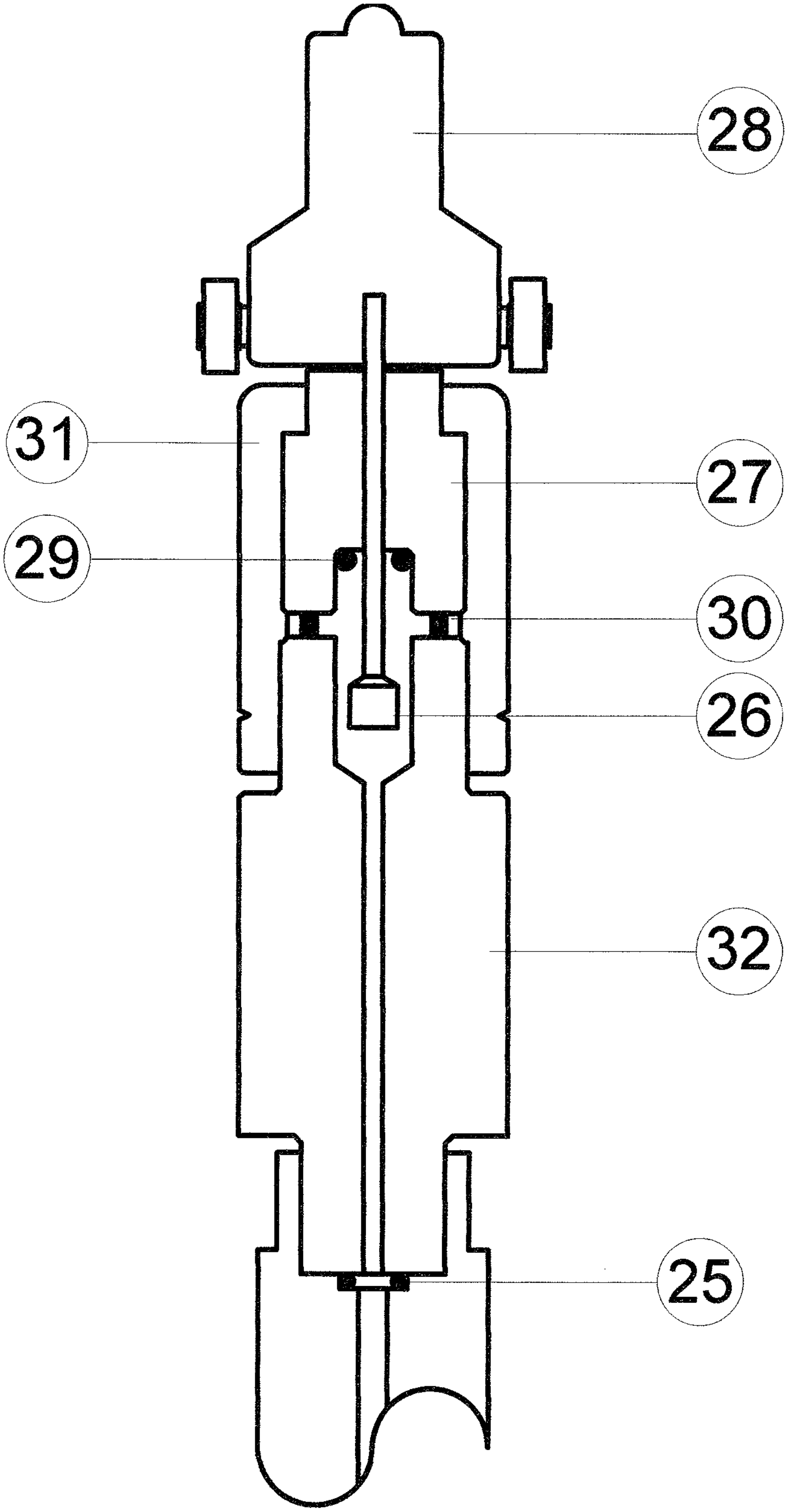
If spin/sensitivity of a cleaned Piston deteriorates quickly then it is likely that the Deadweight Tester system is contaminated and must be completely dismantled, cleaned and rebuilt.

10.11 Piston Increased Fall Rate

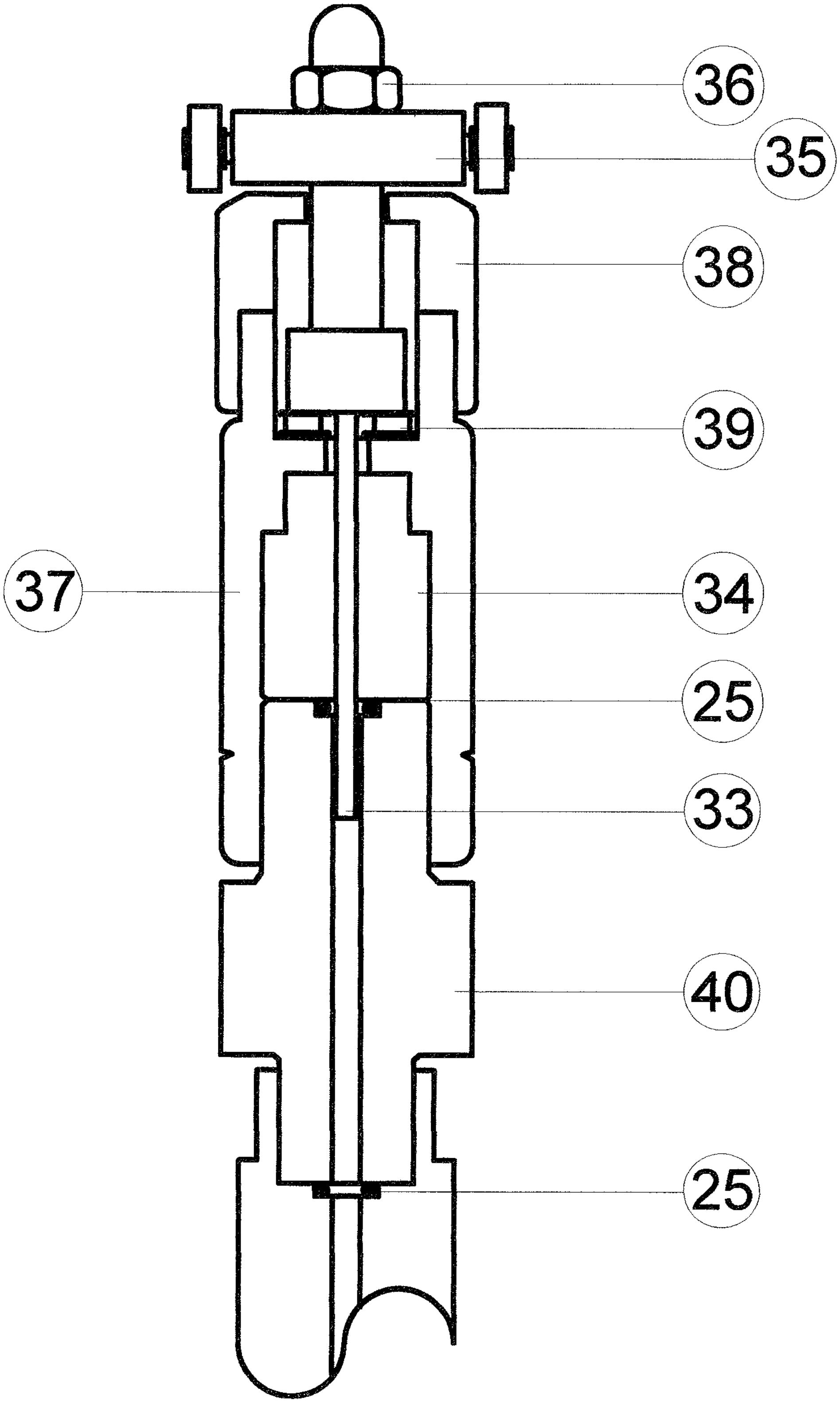
The Piston will always drop slowly due to a small leak between the Piston and Cylinder. However, after re-assembly some air may be trapped under the PCU. The air passing between the piston and cylinder will cause a quicker fall rate. If this is occurring, air bubbles should appear in the fluid where the piston exits the cylinder. Keep the piston spinning and floating to purge the air until the fall rate stabilises.



20	D4116	PISTON	23	D7082	ADAPTOR
21	D4117	CYLINDER	24	B1802	BONDED SEAL
22	D7089	PISTON CAP	25	B3823	'O' RING



25	B3823	'O' RING	29	B1801	'O' RING
26	D4101	PISTON	30	B1902	BONDED SEAL
27	D4102	CYLINDER	31	D4103	SLEEVE NUT
28	D7091	PISTON CAP	32	D7081	ADAPTOR



25	B3823	'O' RING	37	D3813	PISTON NUT A
33	D4101	PISTON	38	D3814	PISTON NUT B
34	D3824	CYLINDER	39	B3825	BEARING
35	D3853	DRIVE COLLAR	40	D3854	ADAPTOR
36	B3856	LOCKNUT			

11.0 FAULT FINDING

11.1 Poor Piston Spin / Sensitivity

IF PISTON IS NOT FREE, DO NOT ROTATE AS DAMAGE MAY OCCUR, DISMANTLE AND CLEAN - SEE SECTION 9.0.

11.1.1 Remove the Weight Carrier Assembly.

11.1.2 Holding the Piston Cap, lift gently up and down. The Piston should slide freely within its Cylinder, if any resistance or a 'gritty' sensation is detected, then it must be cleaned (See Section 10).

11.1.3 If spin/sensitivity of a cleaned Piston deteriorates quickly then it is likely that the operating oil within the Deadweight Tester system is contaminated. This must be drained out, the system cleaned and re-primed with clean oil, see Section 6.

11.2 System Will Not Prime

11.2.1 Check Valve (8) is closed.

11.2.2 Check there is sufficient fluid in the Reservoir (5).

11.2.3 Check for damaged/missing/dirty seal in appropriate Test Port.

11.2.4 Check that the face of the instrument under test is contacting the seal, and that it is not scored or dented.

11.3 System Will Not Pressurise

11.3.1 Check that Valve (8) is closed.

11.3.2 Check for missing/damaged/dirty seal in appropriate Test Port.

11.3.3 Check that the face of the instrument under test is contacting the seal, and that it is not dented or scored.

11.3.4 Check Piston Seal is undamaged.

11.3.5 Check that instrument under test is not leaking.

11.3.6 Check system for leaks by looking for drips at joints whilst continually pressurising. Replace Seal/Part, ensuring that sealing faces are clean and undamaged when re-assembling.

11.4 Handpump Malfunction

11.4.1 Check 11.3

11.4.2a If pumping generates no pressure, then the Inlet Non-Return Valve has probably failed.

11.4.2b This should be disassembled and inspected for dirt or damage to valve seat and Seal. After inspection, clean all parts thoroughly, replace as required and re-assemble correctly.

11.4.3 If the system pressurises and depressurises in conjunction with the downward and upward strokes of the Handpump (9), then the Outlet Non-Return Valve has failed completely. Inspect as per 12.4.2b.

11.4.4 If the Pump Handle rises, then the Outlet Non-Return Valve is leaking. Inspect as per 12.4.2b.

Note: Do not continue to pressurise if Pump Handle rises, as this can damage the pump Inlet Non-Return Valve.

11.5 Piston Drops Quickly

GENERAL: The Piston will always drop slowly due to a small leak between the Piston and Cylinder. This drop rate will never be so quick that a stable reading cannot be made.

11.5.1 If the system has been pressurised quickly then it must be allowed to thermally stabilise. Continue re-floating the Piston until it stabilises, this should take no longer than one minute.

11.5.2 Check 11.3.

11.5.3 IF PISTON HAS JUST BEEN RE-FITTED AFTER CLEANING:
Air pockets can be introduced when re-fitting Piston. This will cause the Piston to drop faster whilst the air bleeds past the Piston and Cylinder.
Continue to re-float the Piston until the drop-rate slows down. If the Piston continues to drop quickly then check the fluid leakage around base of Piston/Cylinder assemblies.
Check for loose/damaged/dirty seal under assembly.
Remove Piston Weight Carrier (11). Tighten, clean or replace Seal as necessary, (See Section 10).

11.5.4 Valve (8) leaking.
Remove Reservoir Bung and observe fluid level, it will rise slowly if the valve leaks.

11.6 Cannot Attain Maximum Pressure Having Screwed Capstan Fully In

11.6.1 Check 11.3 & 11.5.

11.6.2 Ensure that the Capstan (7) is FULLY OUT and the Hand-Pump (9) is used for initial pressurisation. See Section 5.0.

11.6.3 If the instrument under test has a large internal volume or there is air in the system, then re-prime, see Section 5.0, increasing the initial pressurisation with the Handpump (9) from 70 bar to 140 bar.

12.0 SOFTWARE

For full software operation of either calibration programs or sensor programs, refer to the individual manuals supplied.

To enable both programs to run simultaneously load under Windows 95™.
Start programs and click from one to the other.

13.0 OVERHAUL AND RECERTIFICATION

The Deadweight Tester's accuracy depends primarily on the effective area of the Piston and the mass of the Weights.

The Deadweight Tester will require periodic recertification, the frequency of which is dependent on use.
For high accuracy, careful laboratory use, recertify every 2 to 3 years.

The Deadweight Tester should immediately be overhauled and recertified if either:-

(a) The Piston performance degrades (spin, sensitivity, drop rate).
(Ensure that the instructions in Section 9.0, have been carried out).
(b) The Weights are damaged or seriously corroded.

The recalibration frequency must ultimately be specified by the user, with reference to the above comments and any organisational or inspection authority requirements.