5201-5202-5203

User's Manual

Document No. 550001
911000
Printed in the USA.

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CHAPTER 1 - INTRODUCTION

1.1 PURPOSE

DH Model 5200 Pressure Standard is a pneumatically operated deadweight tester used to calibrate test gauges, transducers and transmitters at pressures up to 4 000 psi with a 5201 and 8 000 psi with a 5202 (16 000 psi available on special order).

1.2 OPERATING PRINCIPLE

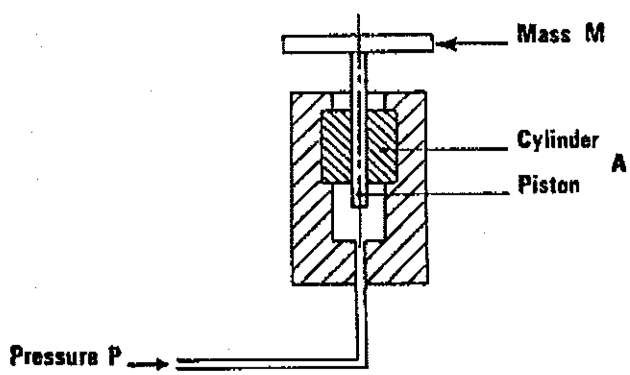
The key component is the mounting post which combines the primary metrological elements:

1) The piston-cylinder which defines an effective area, A.
2) The masses, of global value M, which act upon the piston.

The value of the pressure, P, which puts the piston into equilibrium is given by the formula:

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

g = Acceleration due to gravity



Operating Principal

(User Notes)

CHAPTER 2 - DESCRIPTION

2.1 COMPONENT CHECK LIST

- **Standard**

  Light alloy cast housing with operating elements built in. Supplied in a custom case.

- **Mass Set**

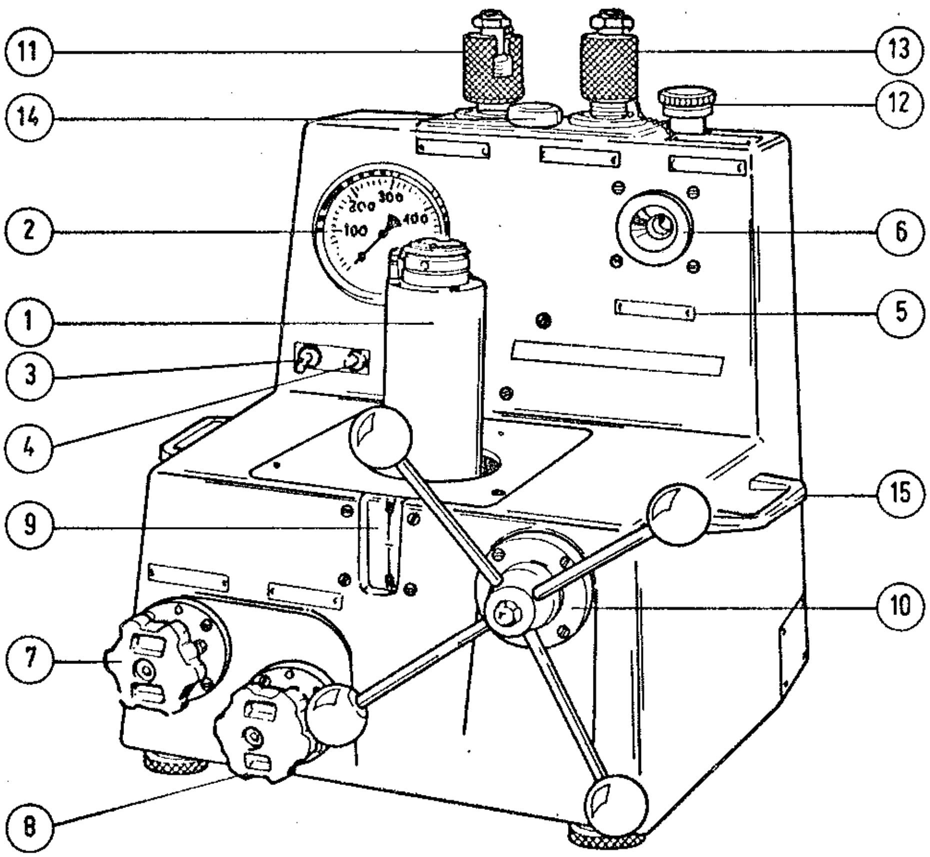
  Set value varies between 20 and 80 kg. Masses are delivered in storage cases.

- **Piston-Cylinder**

  Delivered in a small wooden case with mounting key.

- **Standard Accessories**

  1 Instruction Manual
  1 Calibration Certificate and Technical Data
  1 Liter NUTO HP5
  1 Drive Belt, No. 650
  2 Piston Travel Limit Pins, No. 30199
  4 Leveling Feet Shoes, No. 37613
  1 Plastic Cover, No. 31113
  1 O-Ring Assembly Mounting Tool, No. 40957
  1 O-Ring Assembly for the Quick Connecting Head, No. 41087
  2 O-Rings, No. R13 PC 851
  1 Circlip Special Tool, No. 37351
  1 DH 1500 Cone Gland
  1 DH 1500 Cone Plug
  2 DH 1500 Cone Quick Connectors
  1 Mass Carrying Bell
  1 Oil Run-Off Cup, No. 39509
  1 250 mA Delayed Fuse
  1 Power Supply Cable
  1 RTD Output Cable (S accuracy only)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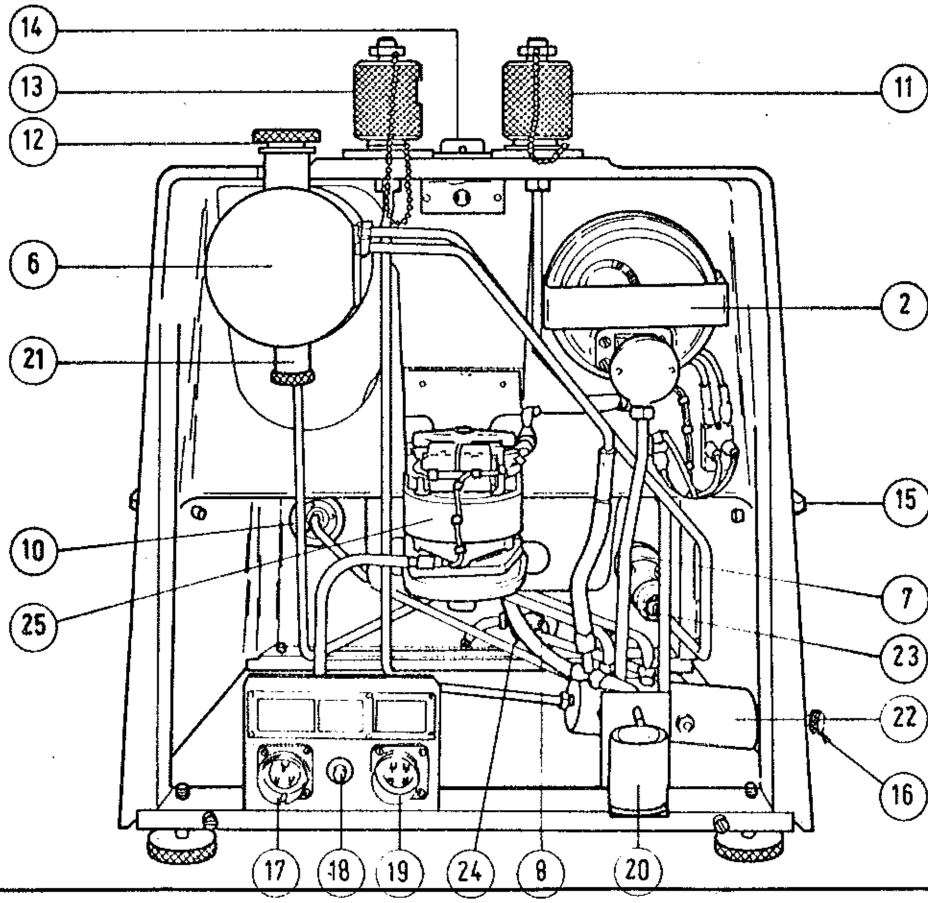
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2.2 SUB-ASSEMBLY LOCATION WITH MANUFACTURER'S REFERENCE NUMBERS

The Model 5200 is made up of a housing into which the following sub-assemblies are integrated:

- **Center**

  1) The Mounting Post into which the piston-cylinder is installed, No. 41074 (No. 41513 for S', S, and S^2 accuracy).

- **Upper Front Face**

  2) Indicator Gauge, No. 232
  3) Power ON/OFF Switch, No. 527
  4) ON/OFF Indicator Light, No. 380627-2
  5) Reference Level Label
  6) Visible Level Reservoir, No. 41076

- **Lower Front Face**

  7) Pressure Inlet Valve, No. 40912
  8) Pressure Exhaust Valve, No. 40912
  9) Piston Displacement Indicator, No. 38576
  10) Variable Volume Screw Press, No. 41506

- **Top**

  11) Pressure Inlet Connecting Head, No. 41951
  12) Visible Level Reservoir Cap, No. 42296
  13) To system under test Connecting Head, No. 41951
  14) Bubble level, No. 41468

- **Right Side**

  15) Carrying Handle

- **Left Side**

  16) Sump Drain-cock, No. 35376
  15) Carrying Handle

- **Rear**

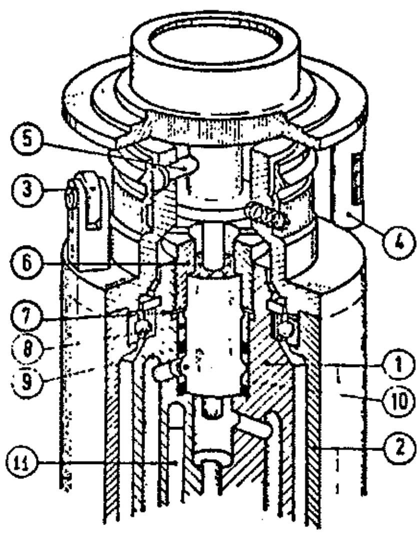
  17) Receptacle for motor power supply cable, No. SLEM-23C
  18) Fuse, No. 19201
  19) RTD Output Receptacle, No. SLEM-25S (S', S and S^2 accuracy only)
  20 Oil Run-off Cup, No. 39509 (delivered with the accessories)

- **Inside**
  7) Pressure Inlet Valve, No. 40912
  8) Pressure Exhaust Valve, No. 40912
  10) Variable Volume Screw Press, No. 41506
  6) Visible Level Reservoir, No. 41076
  2) Indicator Gauge, No. 232
  22) Sump, No. 40888
  21) Drain-cock, No. 39600
  23) Filters, No. 41060
  24) Filters, No. 41060
  21) Motor for piston rotation, No. 39111

The housing is closed in the rear by a panel held by a quick disconnect pin.

2.3 DESCRIPTION OF THE SUB-ASSEMBLIES

- **Mounting Post**

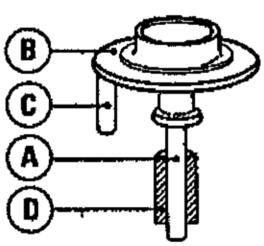


Function: Piston-cylinder mounting post

Description: Stainless steel body (1) over which a pulley (2) is mounted on bearings. The pulley is rotated by the motor using a drive belt. The pulley assures piston rotation using the drive pin (3) which occasionally pushes the pin (4) on the piston plate.

5) Piston travel limit pin
6) Cylinder retaining nut
7) Circlip
8) Spacer
9) O-Ring
10) Spacer
11) Platinum RTD (S accuracy only)

- **Piston-Cylinder**



Function: Fundamental metrological element which transforms the pressure into a measurable proportional force.

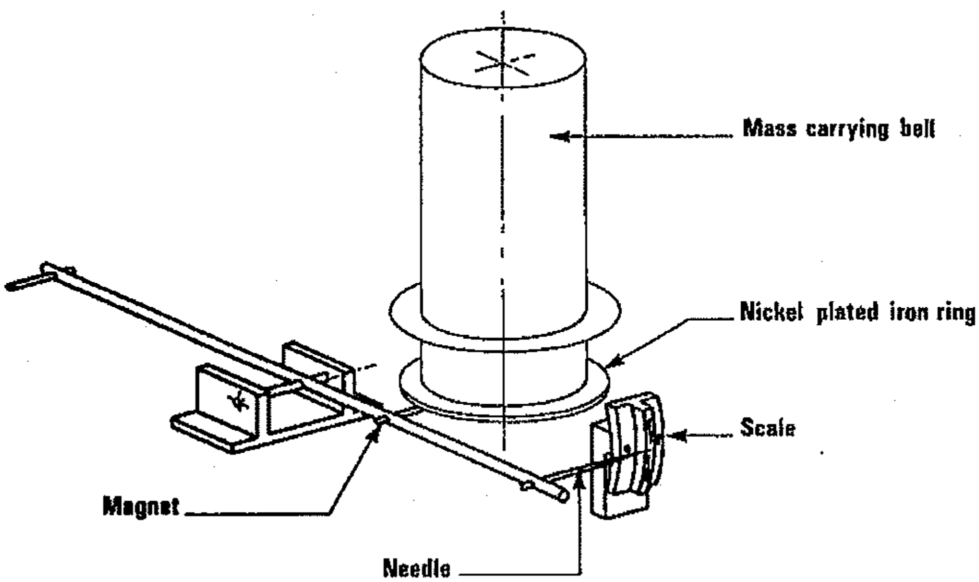
Description: The piston (A) is equipped with a plate (B) on which is mounted a pin (C). The cylinder (D) is always made of tungsten carbide and the piston is made of tungsten carbide or steel.

Piston-cylinders of different effective areas are interchangeable. All pistons have the same mass (0.2 kg) and all cylinders have the same external dimensions.

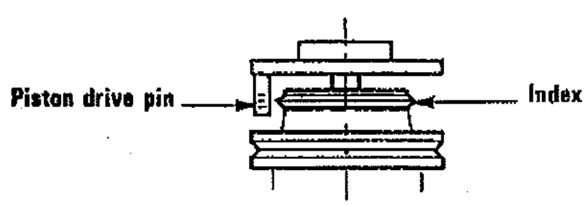
- **Piston Displacement Indicator**

Function: To give a precise indication of piston position and of its movement.

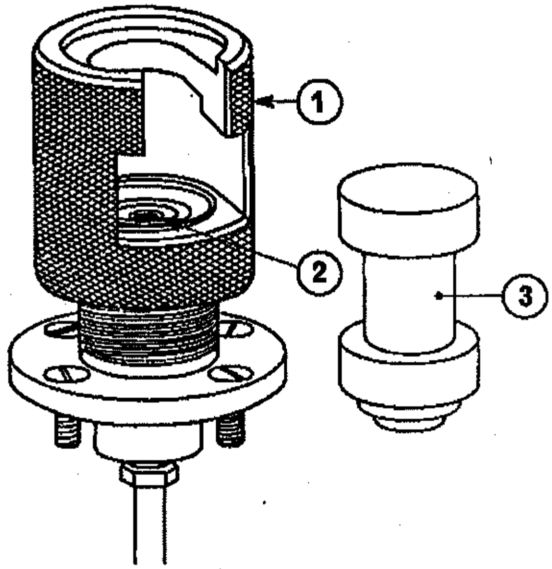
Description: It is a lever that moves in the same direction as the piston. On the lever is a needle which is visible on a scale on the front of the standard. The scale indicates upper and lower end-of-stroke position as well as the mid-stroke equilibrium point. The lever moves via a magnet which tracks a nickel plated iron ring on the mass carrying bell without interfering with its movement. The indication given by the needle is a 4X amplification of actual piston movement.



NOTE: When working without the mass carrying bell, the mid-stroke equilibrium point is identified by the middle marking on the piston drive pin when it is in line with the index ring.



- **Quick-Connecting Head**

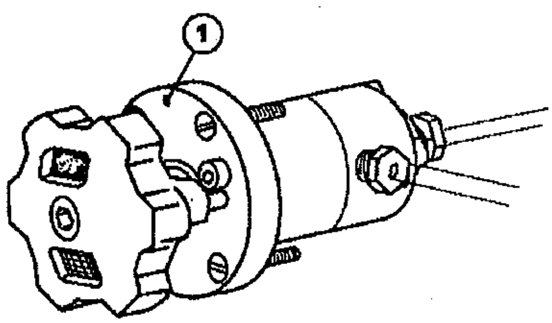


Function: Connection point to the system under test.

Description: A convenient connection which will not be damaged or wear despite many make and break operations. The knurled nut (1) tightens onto a connector (3). An O-ring assembly (2) makes the seal. The knurled nut is tightened by hand even at the highest pressures. The quick-connecting head is an interchangeable sub-assembly but general maintenance requires only the replacement of the O-ring assembly.

NOTE: Many different pressure connectors for the quick-connecting head are available. Please consult CTS Division.

- **Valve**



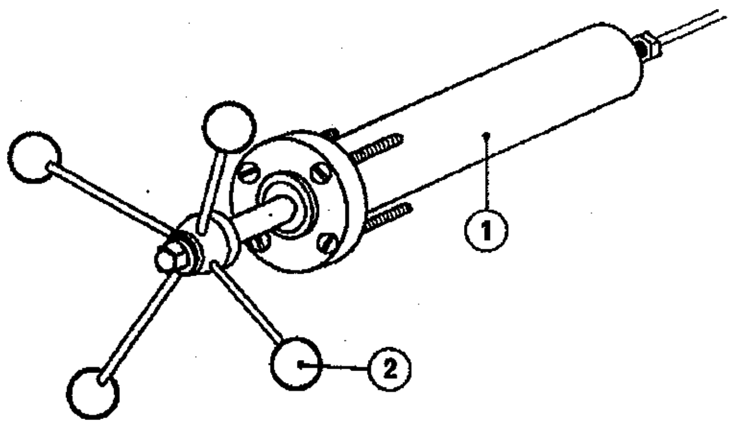
Function: To isolate one part of the pressure circuit from another.

Description: In the closed position, the red label on the handle is across from the white reference dot (1). A Belleville spring pushes the needle onto its seat. The handle feels loose when valve is closed. The opening of the valve is progressive and made by turning the handle clockwise to compress the spring. Rotation of the handle is limited to a half turn by stops. The valves are an interchangeable sub-assemblies.

- **Variable Volume Screw Press**

Function: To adjust pressure.

Description: A cylinder (1) in which a piston is moved by turning a handle (2). Variation of volume for full piston stroke is 15 cm^3. Volume variations for one handle rotation is 0.35 cm^3.

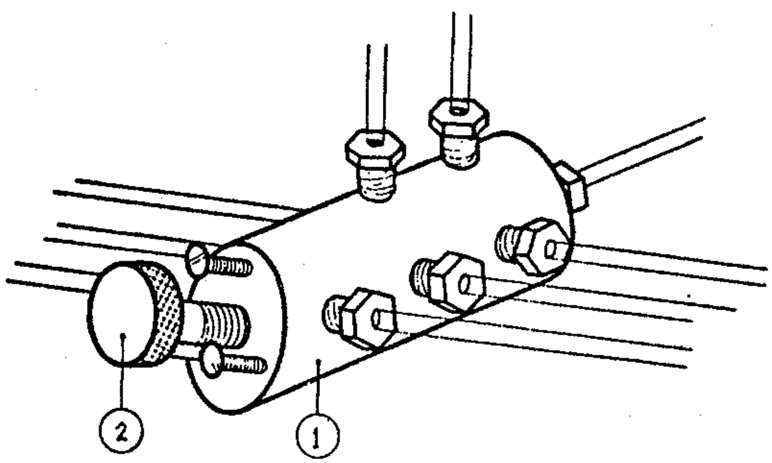


The variable volume is an interchangeable sub-assembly.

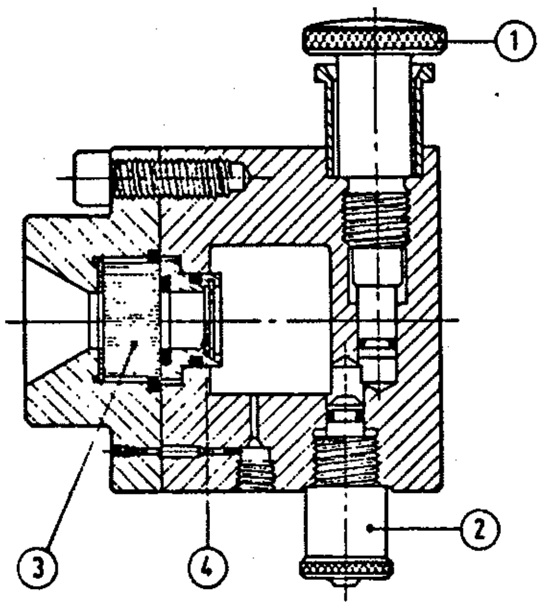
- **Sump**

Function: Located at the low point of the internal circuitry to serve as purge point. Serves as manifold for internal tubing.

Description: A cylinder (1) with the fittings needed for the connection of internal tubing. A drain-cock (2) allows system purge. The sump is an interchangeable sub-assembly.



- **Visible Level Reservoir**



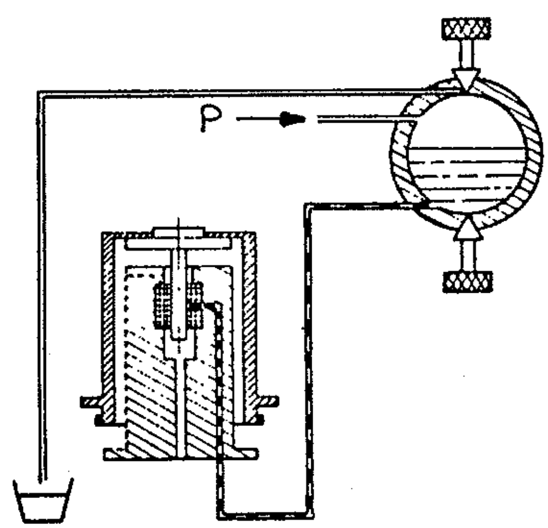
Function: Hold piston-cylinder lubricating fluid.

Description: A cylindrical vessel designed to withstand maximum system pressure. A cap (1) on the top closes the fill opening. A purge screw (2) on the bottom empties the vessel. The front face is a synthetic sapphire (3) which allows visual determination of fill level. The pointer shows a good average fill level. Three lateral connections allow:

- outward flow of lubricant towards the piston-cylinder
- inflow of pneumatic pressure
- fluid overflow in the case of an overfill

The visible level reservoir is an interchangeable sub-assembly.

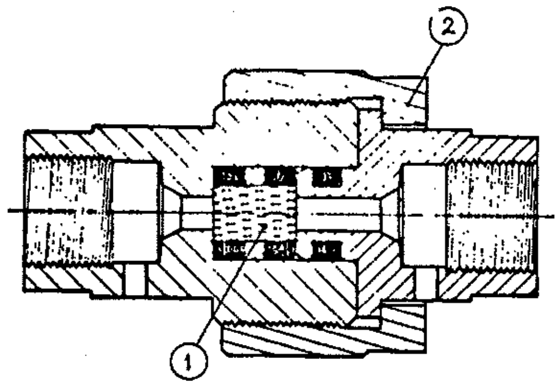
Piston-Cylinder Lubrication Principle



- **Filter**

Function: Protect the system from contaminants in the pressure medium.

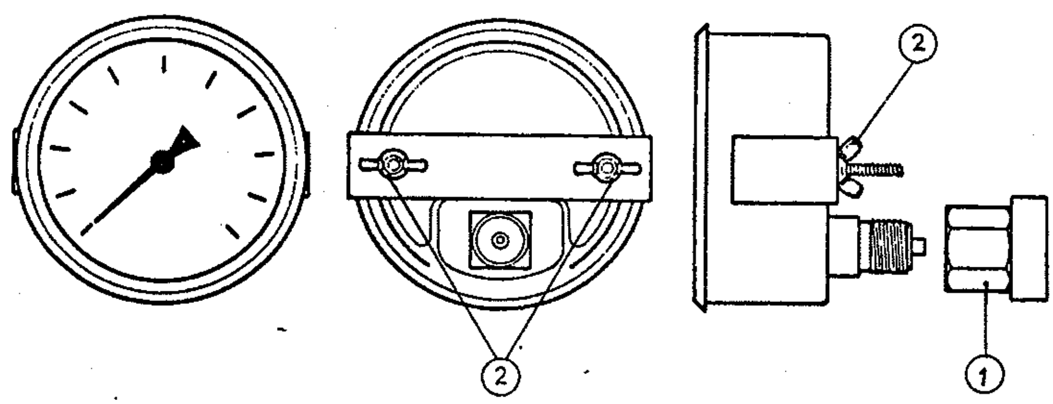
Description: A woven metal mat (1) collects impurities. The nut (2) allows the filter to be opened and cleaned.



- **Indicating Gauge**

Function: Give an immediate visual indication of approximate pressure in the system.

Description: Bourdon Tube Gauge. The gauge is an interchangeable sub-assembly.

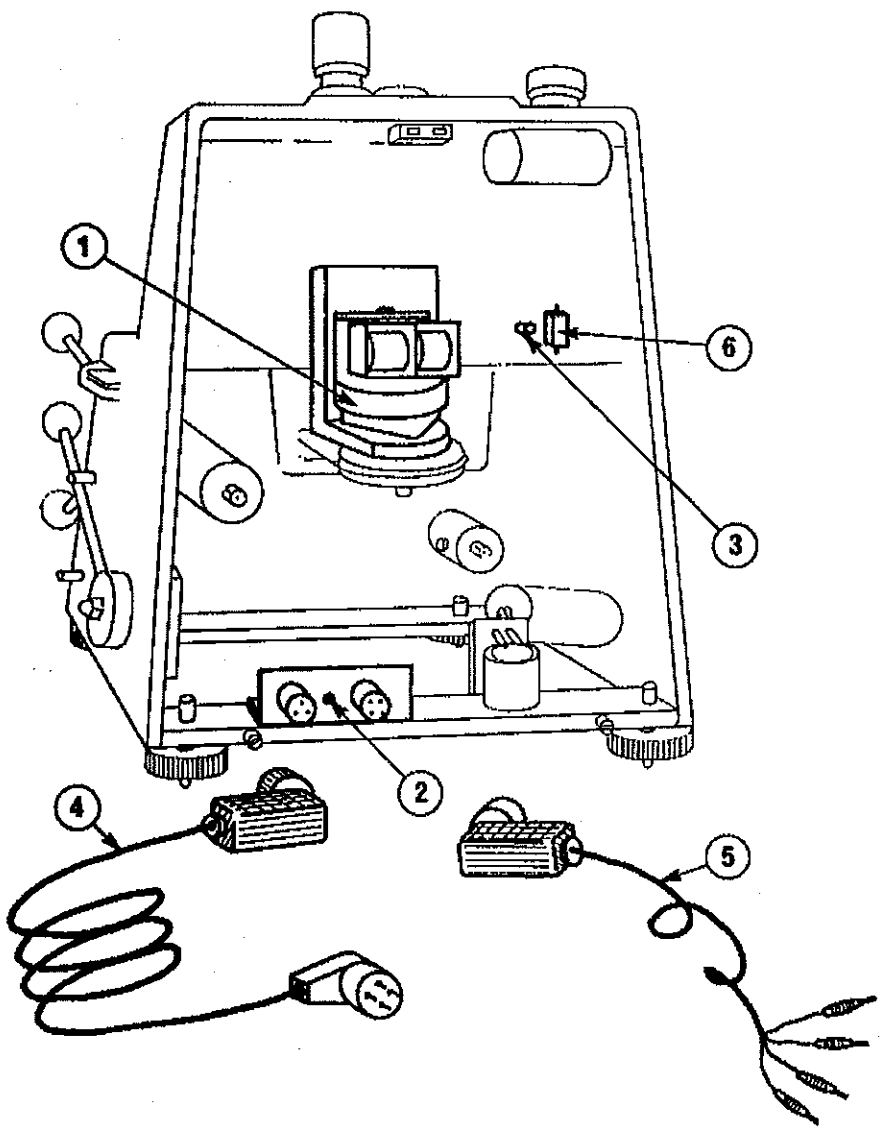


- **Electrical System**

A) **Motor**

Function: For piston rotation using a drive belt and the mounting post pulley.

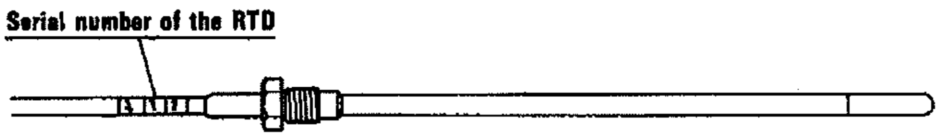
Description: Made up of a 30 RPM squirrel cage motor (1), an ON/OFF switch (6), an ON/OFF indicator light (3), a fuse (2), and a 2.5 meter power supply cable (4) and the RTD cable (5) [S accuracy only]. The motor is an interchangeable sub-assembly.



B) **Temperature Probe (S accuracy only)**

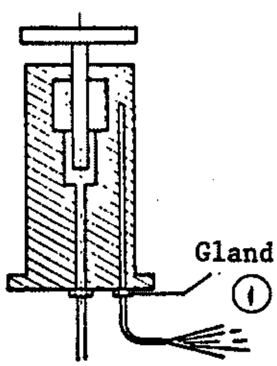
Function: Measure as well as possible the temperature of the piston-cylinder assembly.

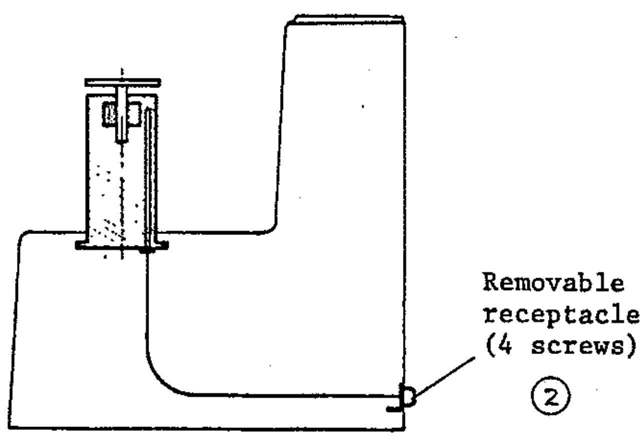
Description: Platinum RTD with 100 ohm nominal resistance at 0°C following DIN standard 43760. The 100 ohm value is given with an uncertainty of ±0.1 ohm which corresponds in temperature to ±0.25°C. The DH Laboratory determines the value of the resistance at 0°C inside the tolerance of the standard with an uncertainty of ±0.02 ohm.



Installation of the Temperature Probe

The temperature probe is mounted in the mounting post as close as possible to the piston-cylinder. It makes possible valid and accurate temperature corrections. The probe is connected to a removable receptacle so that it can be removed and periodically recalibrated.





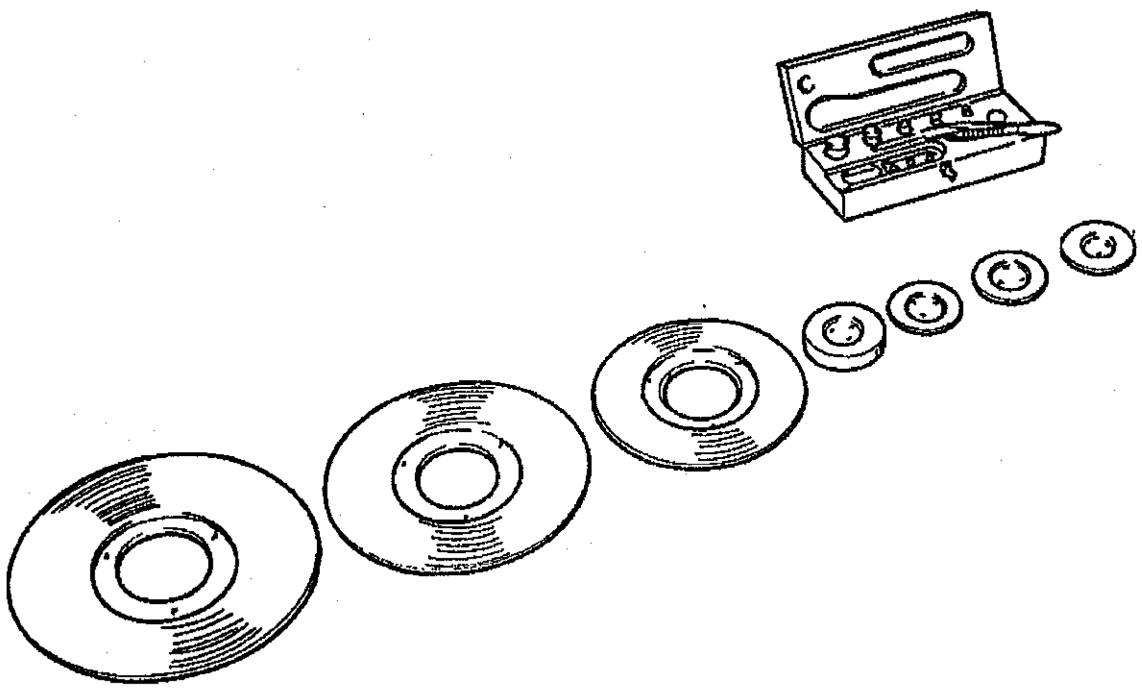
Removing The Probe

- Unscrew the gland (1) under the mounting post.
- Unscrew the 4 screws of the receptacle (2).
- Run the wire through the hole in the receptacle mount.
- Carefully remove the probe from the mounting post.

- **Mass Set**

Function: Define the value M which is subjected to acceleration due to gravity giving the force, F.

Description: Made of non-magnetic stainless steel. Masses of 1 kg and above are discs with a central hole to be slipped onto the mass carrying bell.



NOTE: Masses are engraved in kilograms which makes it possible to interchange piston-cylinders while using the same mass set.

(User Notes)

CHAPTER 3 - INSTALLATION AND START-UP

3.1 THE STANDARD AS DELIVERED

- The standard and its accessories are in a wooden cabinet.
- The four adjustable feet are retracted (screwed in).
- The visible level reservoir is empty.
- Installed in the mounting post is a stainless steel piston-cylinder plug instead of the piston-cylinder.
- The masses are in their carrying cases.
- The piston-cylinder is in its carrying case with the piston-cylinder key.

3.2 INSTALLING THE PISTON-CYLINDER

The overall piston-cylinder installation procedure includes the following:

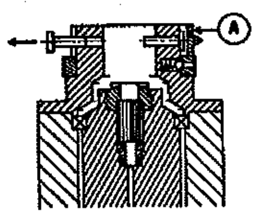
- Setting-up the standard on a rigid table at a convenient height.
- Cleaning the piston-cylinder.
- Removing the piston-cylinder plug.
- Installing the piston-cylinder.
- Filling the lubricant circuit.
- Purging the lubricant circuit.
- Purging the standard.

CLEANING THE PISTON-CYLINDER

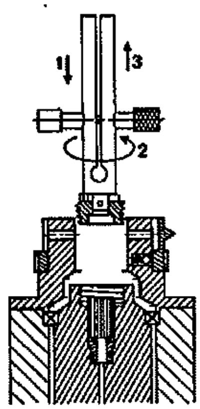
Before installing the piston-cylinder, it must be cleaned with a liquid solvent (for recommendations consult CTS Division).

- Submerge the cylinder in the fluid and wipe the exterior and interior with a clean lint free cloth or tissue.
- Soak the piston in the fluid and wipe it off.
  NOTE: Care should be taken not to submerge the piston plate in the fluid.
- Put the piston in the cylinder. If both elements are properly cleaned, the piston moves freely without resistance in the cylinder.
- Once the elements are clean, lubricate the piston in the oil used in the standard and put the piston into the cylinder so that both pieces are lubricated.

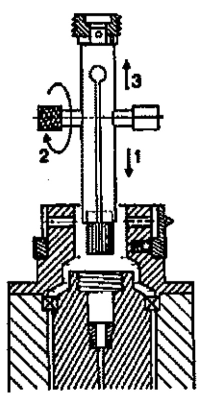
REMOVING THE PISTON-CYLINDER PLUG



1) Rotate ring (A) to expose the head of the piston travel limit pins. Remove each pin as it appears.



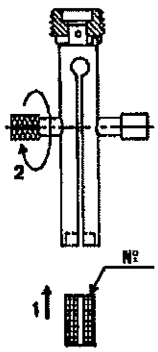
2) Insert the pin end of the piston-cylinder key into the cylinder retaining nut. Unscrew and remove the nut. (A lock ball keeps the nut on the key).



3) Invert the key and set the notched end over the plug and tighten the T handle as indicated. Remove the key and plug.

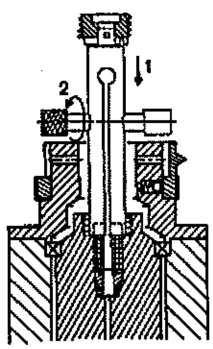
INSTALLING THE PISTON-CYLINDER

- **Installing the Cylinder**

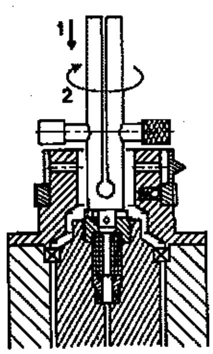


1) Put the cylinder into the notched end of the piston-cylinder key. Tighten T handle.

   NOTE: The cylinder serial number and/or X notation must face upwards after installation. To do so, put this end of the cylinder into the key.



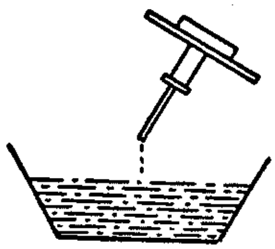
2) Insert the cylinder in the mounting post and loosen the T handle. Remove the key.



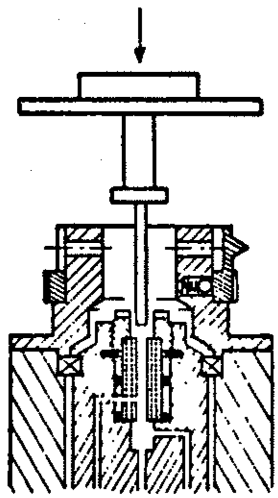
3) Invert tool. Reinstall the piston-cylinder retaining nut. Tighten to the end of its thread.

   NOTE: Hand tighten only. High torque is not required.

- **Installing the Piston**

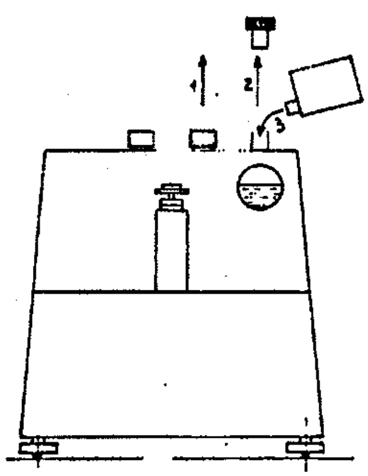


1) Lubrify the piston by dipping it in the fluid.



2) Insert the piston into the cylinder.

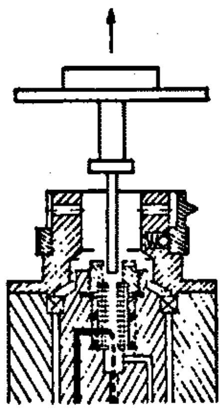
FILLING THE LUBRICATION CIRCUIT



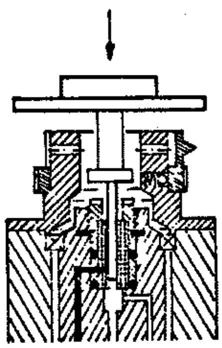
1) Take the plug off the top system pressure connection.
2) Remove the visible level reservoir cap.
3) Slowly fill with fluid until fluid level is just above the pointer index in the window.

PURGING THE LUBRICATION CIRCUIT

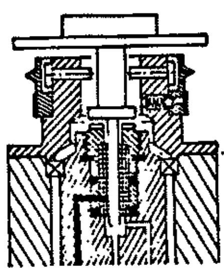
The lubrication circuit must be purged of air.



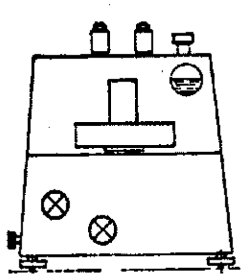
1) Remove the piston and watch for oil run through in the cylinder or an observable level change in the visible level reservoir.



2) When liquid appears at the cylinder or level in the visible level reservoir has changed noticeably, re-insert piston in cylinder.



3) Reinstall the three piston travel limit pins.



4) If necessary, re-adjust fluid level in the visible level reservoir and reinstall cap and then system pressure connection plug.

PURGING THE STANDARD

Once the piston-cylinder has been mounted, the standard must be purged of any lubricating fluid it may contain.

1) Drain standard:
   - Unplug test connecting head.
   - Open sump drain-cock.
   - Allow circuit to drain.

2) Verify that:
   - the visible level reservoir cap is tight.
   - the piston travel limit pins are in place.
   - the mass carrying bell is not on the piston.
   - the plugs are secured in the quick-connecting head.
   - the inlet and exhaust valves are closed.
   - sump drain-cock is closed.

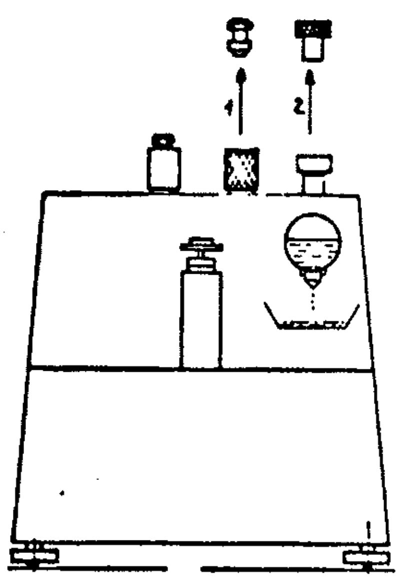
3) Connect a pneumatic supply to the system pressure connection.

4) Open the inlet valve to admit pneumatic pressure into the standard up to a pressure of about 150 psi. Close the inlet valve.

5) Vent the pressure by loosening the drain-cock on the clarification chamber. Fluid, if present, will come out with the pressure.

3.3 REMOVING THE PISTON-CYLINDER

The standard must be at atmospheric pressure.



1) With the system pressure connection open remove the visible level reservoir cap.

2) Loosen the visible level reservoir drain-cock and drain fluid in the reservoir into a cup.

3) Open sump drain-cock.

4) Proceed in reverse of piston-cylinder installation.

3.4 START-UP

The description below assumes the piston-cylinder is already installed.

1) Level the standard using the 4 leveling feet and the bubble level:
   - Unscrew all four feet a few turns.
   - Screw in completely the front right foot.
   - Push down the left rear of the standard to stabilize it on the three feet that are screwed out.
   - Put the bubble into proper position on the right/left axis using the front left foot.
   - Put the bubble into the reference circle using the right rear foot.
   - Unscrew the front right foot to stabilize the standard.

2) If you have a standard with a switchable voltage motor, select the appropriate voltage (110V or 220V) with the switch on the inside of the standard.

3) Connect the power supply cable to the receptacle on the rear of the standard. Plug the cable into the power supply.

4) Connect the temperature probe cable to the receptacle on the rear of the standard and to a digital ohmmeter (S accuracy only).

5) Switch the motor on to rotate the piston.

6) Place the mass carrying bell on the piston plate and load four 2 kg masses on the bell.

7) Slowly admit pressure to the system until the piston rises.

8) Let the system sit for several minutes to assure proper seating of internal elements and to check for leaks.

9) Unscrew the variable volume until the piston comes back down.

10) Vent pressure to return system pressure to atmospheric.

3.5 CALIBRATION PROCEDURE

1) Connect the instrument to be calibrated to the "gas pressure" connecting head.
2) Screw the variable volume 3/4 out.
3) Load the mass carrying bell with additional mass to correspond to the first pressure increment desired.
4) Slowly open the "gas admission" (inlet) valve until the piston moves upward.
5) Adjust the variable volume to adjust pressure until piston is in float position.
6) After stabilization, record output of instrument under test.
7) Add the masses required to obtain the next pressure increment desired.
8) Using the "gas admission" valve and variable volume, adjust pressure until piston is in float position.
9) Repeat Steps 6, 7 and 8 for each increment.
10) For descending pressures, proceed in the same manner using the "gas exhaust" valve. Bring the piston to bottom end-of-stroke position before opening the "gas exhaust' valve completely.

3.6 PARTICULARITIES OF PNEUMATIC OPERATION

Rapid variations of pneumatic pressure create significant changes in the temperature inside the standard. When added to the expansion and contraction of the internal elements of the standard, the result is that several minutes may be required to find stability after a pressure change.

3.7 PRECAUTIONS TO BE TAKEN TO ASSURE GOOD MEASUREMENTS

1) Clean the piston-cylinder thoroughly before installation.
2) Mount the cylinder in the correct direction (serial number on top).
3) Install the piston travel limit pins.
4) Check fluid level in the visible level reservoir.
5) Tighten the visible level reservoir cap.
6) Purge the standard.
7) Check that the standard is level.
8) Check power supply voltage.
9) Check that the piston is rotating.
10) Always put the piston in bottom end-of-stroke position before venting pressure.
11) Calibrate an instrument in its usual operating position.
12) Check entire system for leaks.

3.8 SHUT-DOWN PROCEDURE

1) Close the gas cock of the pressure source.
2) Vent system to atmospheric pressure by opening the exhaust valve.
3) Open the inlet valve.
4) Screw in the variable volume.
5) Turn off the motor.
6) Return masses to their carrying cases.
7) Cover the standard with its plastic case.

3.9 PERIODIC MAINTENANCE

1) Empty the oil run-off cup at the back of the standard. NEVER RE-USE THIS OIL.
2) Purge the system at the sump drain-cock.

3.10 PERIODIC OPERATIONAL CHECK

For regular use, it is recommended to return the standard to DHI every three years for a system overhaul. Production and high volume applications may require more frequent maintenance. Contact CTS Division for on-site maintenance.

3.11 RECALIBRATION OF PISTON-CYLINDER AND MASSES

Periodic recalibration of the piston-cylinder and masses assures the long term reliability and optimal metrological performance of the system. Though other organizations can perform these calibrations, it is recommended that the DHI Calibration, Test and Service Division be used in order to receive data which allows the exploitation of piston K_N factors and whole number masses. The DHI calibration chain also documents long term repeatability of the system well inside of accuracy tolerances.

- **N Class Standards** - Two years after delivery, a complete recalibration by the CTS Division is advised. If no significant change from original data has occurred, adoption of a three year calibration cycle is recommended.

- **S', S and S^2 Class Standards** - The first and second year after delivery, a complete recalibration by the CTS Division is advised. If no significant change from original data has occurred, adoption of a two year calibration cycle is recommended.

3.12 MOVING THE STANDARD

When moving the standard, complete the following:

1) Remove the piston-cylinder.
2) Store the piston and cylinder in their case.
3) Install the piston-cylinder plug into the mounting post.
4) Tighten the oil reservoir cap.
5) Plug the quick-connecting head.

3.13 SHIPPING THE STANDARD

When shipping the standard, the special shipping crates provided should be used.

1) Follow Moving the Standard instructions #1 through 5 (see Section 3.12).
2) Completely screw in the four adjustable feet.
3) Put the standard, the piston-cylinder, and the masses in their carrying cases.
4) Store the standard's accessories in the top of the standard's case.
5) Pack all the cases in their shipping crates.

3.14 STORING THE STANDARD

Follow Shipping the Standard instructions (see Section 3.11). Storage temperature: -15°C +65°C (+5 to +150°F).

CHAPTER 4 - METROLOGICAL THEORY OF THE PRESSURE STANDARD

4.1 FUNDAMENTAL THEORY

The formula which gives the pressure at the reference level of the standard is:

$$P = \frac{Mg\left(1 - \frac{\rho_a}{\rho_m}\right)}{A_{(\theta)}}$$

Where:

- P: pressure
- M: total mass on the piston
- g: acceleration due to gravity
- ρ_a: air density
- ρ_m: mass density
- $A_{(\theta)}$: effective area of the piston cylinder at temperature θ.

The expression $1 - \frac{\rho_a}{\rho_m}$ is the correction due to the effect of air buoyancy on the masses. Under standard gravity and air density conditions, pressure is defined as:

$$P = \frac{M\ gn\left(1 - \frac{\rho_a}{\rho_m}\right)}{A_{(\theta)}}$$

Where:

- gn: 9.80665 m/s^2 (standard gravity)
- ρ_a: air density at 20°C and atmospheric pressure of 1013.25 mbar: 1.2 kg/m^3
- ρ_m: density of stainless steel: 7920 kg/m^3
- $A_{(\theta)}$: effective area of the piston cylinder at temperature θ.

In writing:

$$K_{N(\theta)} = \frac{gn\left(1 - \frac{\rho_a}{\rho_m}\right)}{A_{(\theta)}} \qquad Eq.4.1$$

One obtains:

$$P = K_{N(\theta)}\ x\ M \qquad Eq.4.2$$

The effective areas of DHI piston-cylinders is such that K_N is a whole number when θ = 20°C.

$K_{N(20)}$ is called the normal conversion coefficient. It is a whole number for each piston-cylinder such that under standard conditions a mass of 1 kg is put into equilibrium by a pressure of $K_{N(20)}$ psi or $K_{N(20)}$ MPa.

Pneumatic piston-cylinders are mounted in a re-entrant mounting system which makes the change of effective area with pressure over 40 kg operating range negligible relative to the uncertainty on P. When using more than 40 kg of mass, refer to the piston-cylinder calibration certificate to correct for changes of effective area with pressure.

Piston-cylinders, for this model, are available with the following $K_{N(20)}$:

<u>Measurements in psi</u>

$K_{N(20)}$ = 20 psi/kg
$K_{N(20)}$ = 50 psi/kg
$K_{N(20)}$ = 100 psi/kg
$K_{N(20)}$ = 200 psi/kg
$K_{N(20)}$ = 300 psi/kg

<u>Measurements in MPa</u>

$K_{N(20)}$ = 0.1 MPa/kg
$K_{N(20)}$ = 0.2 MPa/kg
$K_{N(20)}$ = 0.5 MPa/kg
$K_{N(20)}$ = 1.0 MPa/kg
$K_{N(20)}$ = 2.0 MPa/kg

CORRECTION FOR ACCELERATION DUE TO GRAVITY

At the location where the standard is used, the local gravity, gl, is usually different from standard gravity, gn. This gives:

$$P = \frac{M\,gl\left(1-\frac{\rho_a}{\rho_m}\right)}{A_{(\theta)}}$$

By writing:

$$K_{1(\theta)} = \frac{gl\left(1-\frac{\rho_a}{\rho_m}\right)}{A_{(\theta)}} \qquad Eq.\,4.3$$

From which:

$$K_{1(20)} = \frac{gl\left(1-\frac{\rho_a}{\rho_m}\right)}{A_{(20)}}$$

One can write:

$$K_{1(20)} = \frac{gl\left(1-\frac{\rho_a}{\rho_m}\right)}{A_{(20)}} = \frac{gn\left(1-\frac{\rho_a}{\rho_m}\right)}{A_{(20)}} \; x \; \frac{gl}{gn} = K_{1(20)}\frac{gl}{gn} \qquad Eq.\,4.3'$$

With:

$$Cg = \frac{gl}{gn}$$

C_g is the gravity correction. This value can be found in the C_g annex.

$K_{1(20)}$ is called the local conversion coefficient, which is defined by the piston-cylinder used and the location of use. For a given location K_1 is a constant:

$$K_{1(20)} = K_{N(20)} \; x \; Cg \qquad Eq. 4.4$$

CORRECTION OF EFFECTIVE AREA AS A FUNCTION OF TEMPERATURE AND PRESSURE

When the temperature is other than 20°C the change in effective area is defined by the following formula:

$$A_{(\theta)} = A_{(20)} \, [1 + (\alpha_C + \alpha_P) \, (\theta - 20)] \qquad Eq. 4.5$$

Where:

- $A_{(\theta)}$: effective area of the piston cylinder at temperature θ
- $A_{(20)}$: effective area of the piston cylinder at temperature 20°C
- α_C: thermal expansivity of the cylinder
- α_P: thermal expansivity of the piston
- θ: temperature

GENERAL FORMULA

From Equations 4.3, 4.3', and 4.5, one obtains:

$$K_{1(\theta)} = K_{1(20)} \, [1 - (\alpha_P + \alpha_C) \, (\theta - 20)]$$

If

$$C_\theta = 1 - (\alpha_P - \alpha_C)(\theta - 20)$$

then

$$K_{1(\theta)} = K_{1(20)} C_\theta \qquad Eq. 4.6$$

C_θ is the correction coefficient for temperature. This value can be found in the annex. Using Equations 4.6 and 4.4, it is possible to calculate P.

$$K_{1(20)} = K_{N(20)} \; x \; Cg$$

$$P = K_{N(20)} \; x \; Cg \; x \; C_\theta \; x \; M$$

AIR HEAD CORRECTION

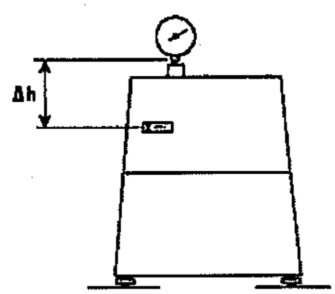
The calculations on the previous page define the pressure at the bottom of the piston. The position of the bottom of the piston, when the piston is in mid-float position, is identified by a label "reference level" on the standard's housing.

Generally, the instrument under test is not at the same height as the standard's reference level. Therefore, a correction defined by the following formula must be made:

$$\Delta P = \rho \; x \; g \; x \; \Delta h$$

Where:

- ΔP: fluid head correction.
- ρ: density of the fluid at operating pressure P
- Δh: difference in height between the reference levels of the standard and the instrument under test.
- g: acceleration due to gravity



The ΔP correction is negative if the instrument under test is above the standard's reference level:

$$P \text{ instrument under test} = P \text{ standard} - \Delta P$$

The ΔP correction is positive if the instrument under test is beneath the standard's reference level:

$$P \text{ instrument under test} = P \text{ standard} + \Delta P$$

4.2 PRESSURE CALCULATION

The following values are given with the standard's calibration certificates:

- $A(mes)_{(20)}$: Measured effective area at 20°C
- $K_{N(20)}$: Normal conversion coefficient at 20°C
- α_P: Thermal expansivity of the piston
- α_C: Thermal expansivity of the cylinder
- R_o: Resistance value of the RTD at 0°C

Pressure is calculated as follows:

CALCULATION OF THE LOCAL CONVERSION COEFFICIENT AT 20°C

$$K_{1(20)} = K_{N(20)}\ x\ Cg$$

C_g: correction coefficient for gravity for a given location
$K_{I(20)}$: is a constant for one location

CALCULATION OF THE PRESSURE AT THE REFERENCE LEVEL OF THE STANDARD

$$P = K_{1(\theta)}\ x\ M$$

Where

$$K_{1(\theta)} = K_{1(20)}\ x\ C_\theta\ x$$

M: total mass on the piston

CALCULATION OF THE PRESSURE AT THE HEIGHT OF THE INSTRUMENT UNDER TEST

$$P\ instrument\ under\ test = P\ standard + \Delta P$$

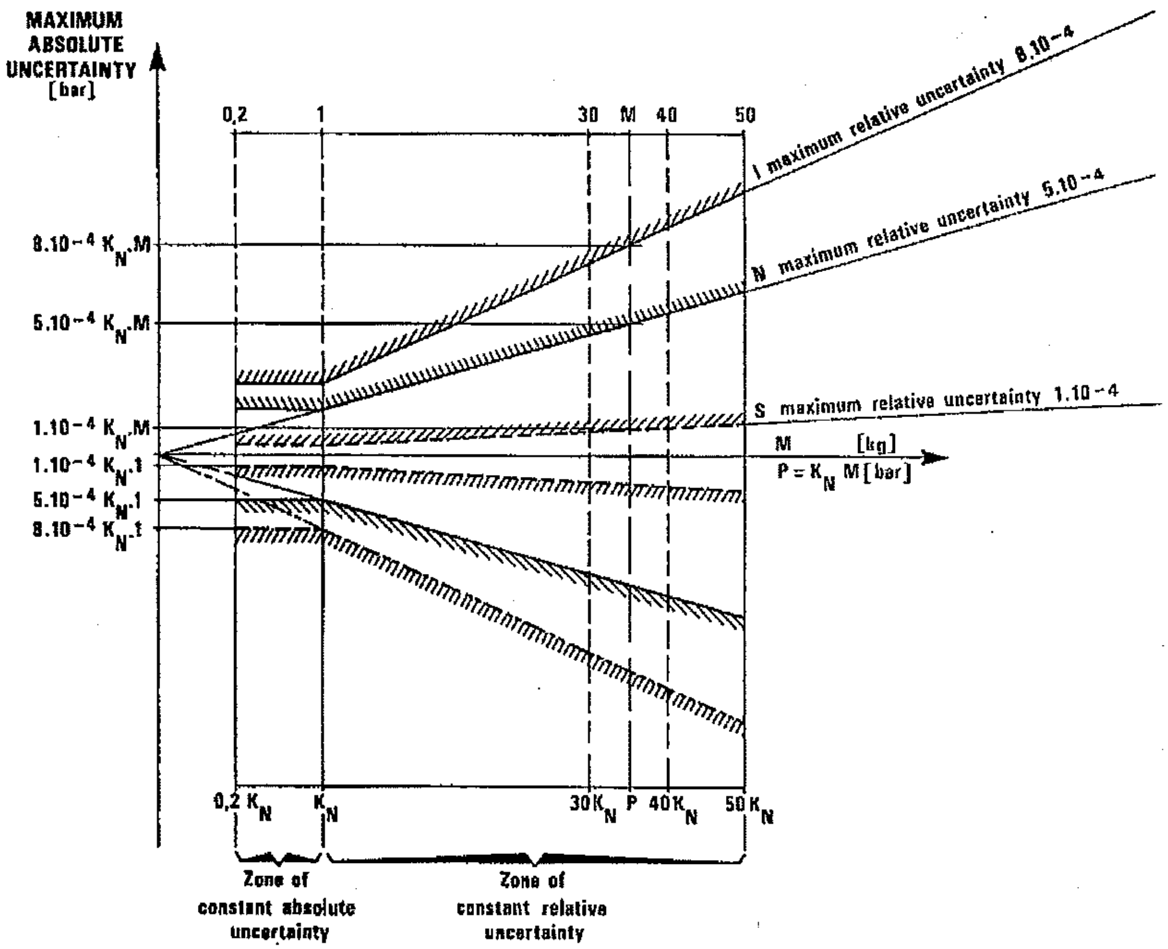
ΔP is the fluid head correction which can be positive or negative.

4.3 ACCURACY OF THE PRESSURE STANDARDS

The accuracy class of a pressure standard defines the relative uncertainty on a measured pressure. The lower limit is the pressure which puts into equilibrium 1 kg of mass, which is a value equal to the K_N of the piston-cylinder used. 1 kg is defined by the mass of the piston plus the mass of the mass carrying bell.

At 1 kg and above, there is enough rotational inertia to assure good mobility of the piston. In addition, the piston displacement indicator can be used.

Reference pressures between 0.2 kg (the piston alone) and 1 kg (piston + bell) can be defined. In this range, however, there is a constant absolute error equal to the relative error on the pressure defined by 1 kg.



4.4 TEMPERATURE PROBE (S accuracy only)

MEASURING PRINCIPAL

In the range of 0 - 40°C, the temperature is proportional to the change in resistance of the platinum RTD following the formula:

$$\theta = \frac{R_\theta - R_o}{0.389}$$

Where:

θ:	temperature in °C
R_θ:	read resistance of the platinum RTD at temperature θ
R_o:	resistance of the platinum RTD at 0°C (supplied by DH)
0.389:	conversion coefficient of ohms to °C following DIN norm 43760

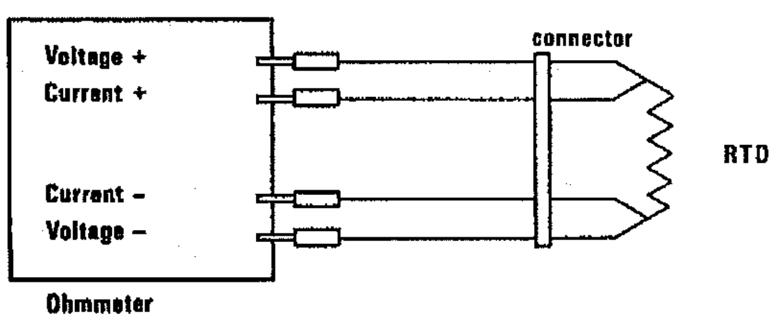
The resistance used must be the resistance of the platinum RTD only; excluding the resistance of the read-out cable. This is why a 4-wire cable is used.

- Two wires are used to give a constant power supply to the RTD (5 mA max).
- Two wires are used to measure the resistance of the RTD.

MEASUREMENTS

A) Using an ohmmeter allowing 4-wire measurements. In this case, there is a direct read-out of the *R* value.

- <u>Connecting the temperature probe</u>
  - Connect the read-out cable to the receptacle on the back of the standard.
  - Connect the 4 plugs of the cable to a digital ohmmeter (supply current must not exceed 5mA).



  - The ohmmeter should be calibrated to read a value of about 100 ohm with an accuracy of ±0.01 ohm.

Example of a calculation

Value read on the ohmmeter: 107.32
Ohmic resistance at 0°C: 99.98

$$\theta = \frac{107.32 - 99.98}{0.389} = 18.87°C$$

B) Using an ohmmeter allowing only 2-wire measurements: The resistance measured is the resistance of the RTD plus the resistance of the connecting leads. To diminish the effect of the resistance of the connecting leads, leads R_1 and R_2 and leads R_3 and R_4 should be connected in parallel.

R_1 red plug R_2 red plug	---	same end of the RTD
R_3 blue plug R_4 blue plug	---	same end of the RTD

Since the length of the leads is approximately equal, we can say:

$$R_1 = R_2 = R_3 = R_4$$

When the leads are in parallel, the effect of the resistance of the leads in the measurement is:

$$\frac{R_1 + R_2}{4} \quad \text{for leads } R_1 \text{ and } R_2$$

$$\frac{R_3 + R_4}{4} \quad \text{for leads } R_3 \text{ and } R_4$$

given:

$$\frac{R_1 + R_2}{4} + \frac{R_3 + R_4}{4}$$

Therefore, from the value measured in 2 leads, the value:

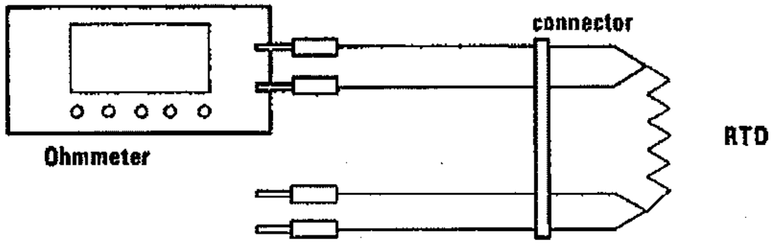
$$\frac{R_1 + R_2 + R_3 + R_4}{4}$$

must be subtracted to obtain the value of the resistance of the RTD.

- **Determination Of The $R_1 + R_2$ Resistance Value (Red Plugs)**
    - Put the ohmmeter in measuring mode.
    - Connect the temperature probe cable to the receptacle on the standard.
    - Measure the resistance between the two red leads.
    - Read the value (about 0.3 Ω).

- **Determination Of The $R_3 + R_4$ Resistance Value (Blue Plugs)**

  Proceed as for $R_1 + R_2$ above using the blue plugs rather than the red plugs. Resistance should be about 0.3 Ω.



- **Measuring The Resistance Of The RTD To Determine The Temperature**

  - Parallel the two red plugs by plugging one into the other.
  - Parallel the two blue plugs by plugging one into the other.
  - Connect the red plugs and blue plugs to the ohmmeter (take care that there is no contact between the red and blue plugs).
  - Read the resistance value (about 107 Ω)

$$R = R_0 - \left(\frac{R_1+R_2}{4}+\frac{R_3+R_4}{4}\right)$$

- **Temperature Calculation**

$$R_\theta = R - \left(\frac{R_1+R_2}{4}+\frac{R_3+R_4}{4}\right)$$

$$\theta = \frac{R_\theta - R_o}{0.389}$$

- **Example Of Temperature Calculation**

Measure: $R_1 + R_2 = 0.3$ (see previous page)
$R_3 + R_4 = 0.4$ (see previous page)

$$R_\theta - \left(\frac{R_1+R_2}{4}\right)+\left(\frac{R_3+R_4}{4}\right) = 107.5\,\Omega$$

from which: $R_\theta = 107.5 - \left(\frac{R_1+R_2}{4}+\frac{R_3+R_4}{4}\right)$

$$R_\theta = 107.5 - \left(\frac{0.3}{4}+\frac{0.4}{4}\right)$$

$$R_\theta = 107.5 - (0.08 + 0.1)$$

$$R_\theta = 107.5 - 0.18$$

$$R_\theta = 107.32$$

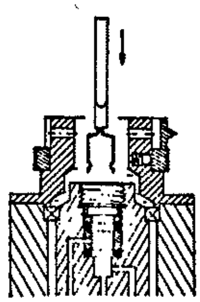
For ohmic resistance of the RTD at 0°C of 99.98 (value furnished by DHI given on a stamped label on the back of the standard and in the Standard's Technical Data) the temperature is:

$$\theta = \frac{R_\theta - R_o}{0.389} = \frac{107.32 - 99.98}{0.389} = 18.87°C$$

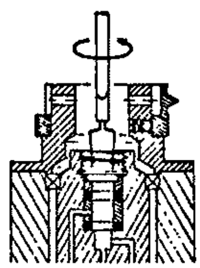
- **Remark**
  - For a given RTD cable used with a given standard, the values of $R_1 + R_2$ and $R_3 + R_4$ are constants.
  - Using a different cable on the same standard or vice-versa, changes the values of $R_1 + R_2$ and $R_3 + R_4$.
  - The temperature value obtained using this method is accurate to ±1°C which corresponds to ±0.001% on the effective area of the piston.

CHAPTER 5 - MAINTENANCE

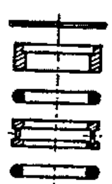
5.1 CHANGING THE MOUNTING POST O-RING ASSEMBLY



1) Remove the cylinder and screw the special tool into the notches in the circlip.



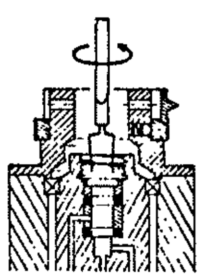
2) Remove the circlip by rotating the tool.



3) Remove the first spacer, the first O-ring, the second spacer and the second O-ring. Replace the O-rings and re-assemble.

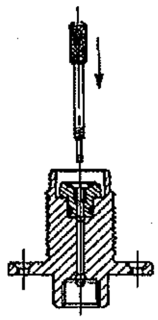
NOTE: Arrange the O-rings and spacers as shown.

Circlip, No. 36866
Spacer, No. 30188
O-ring, R-13
Spacer, No. 30187
O-ring, R-13

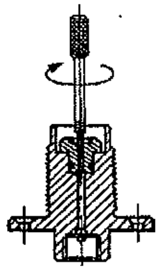


4) Reinstall the circlip to the bottom of the thread.

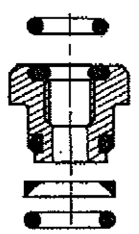
5.2 CHANGING THE QUICK-CONNECTING HEAD O-RING ASSEMBLY (No. 41087)



1) Remove the knurled nut from the quick-connecting head.



2) Screw the special tool into the O-ring assembly and pull upwards to remove the O-ring assembly.

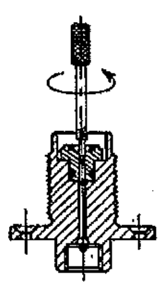


Upper O-ring, No."R2".

O-ring assembly, No. 41087.

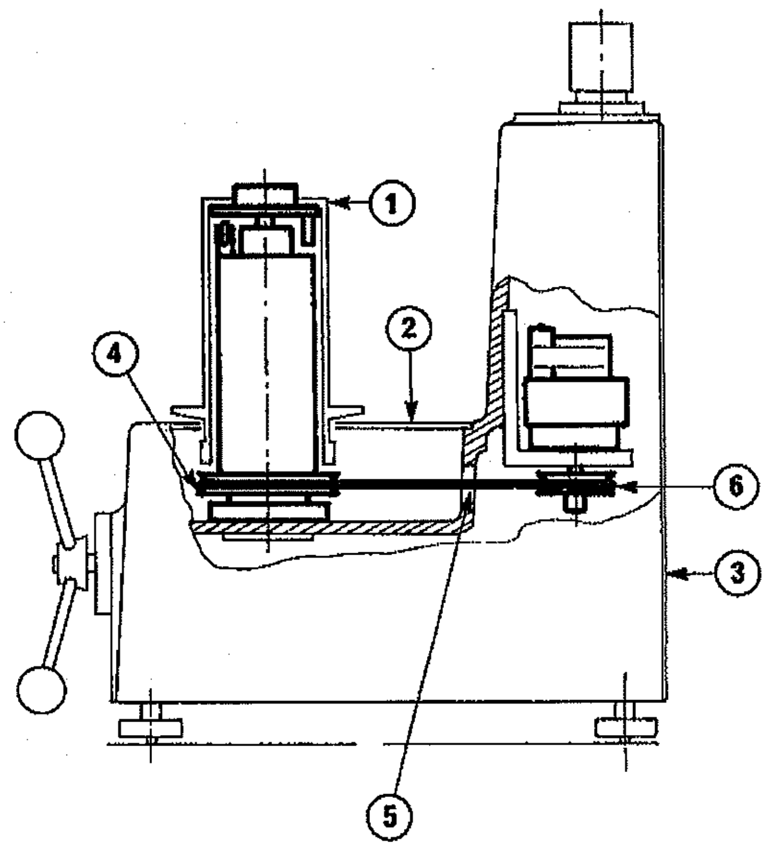
Anti-extrusion ring, No. 40900.

Lower O-ring, No."R5".



3) Screw a new O-ring assembly onto the special tool, push it into quick-connecting head. Unscrew and remove the special tool.

5.3 REPLACING THE DRIVE BELT



1) Remove the mass carrying bell (1), the upper cover (2) and the rear cover (3).
2) Remove the used belt.
3) Slip the new belt over the pulley (4) and position it in the groove. Pass the belt through the opening (5) and position it in the groove of the motor pulley (6).
4) Reinstall the protective covers, (2) and (3).

(User Notes)

CHAPTER 6 - TROUBLESHOOTING

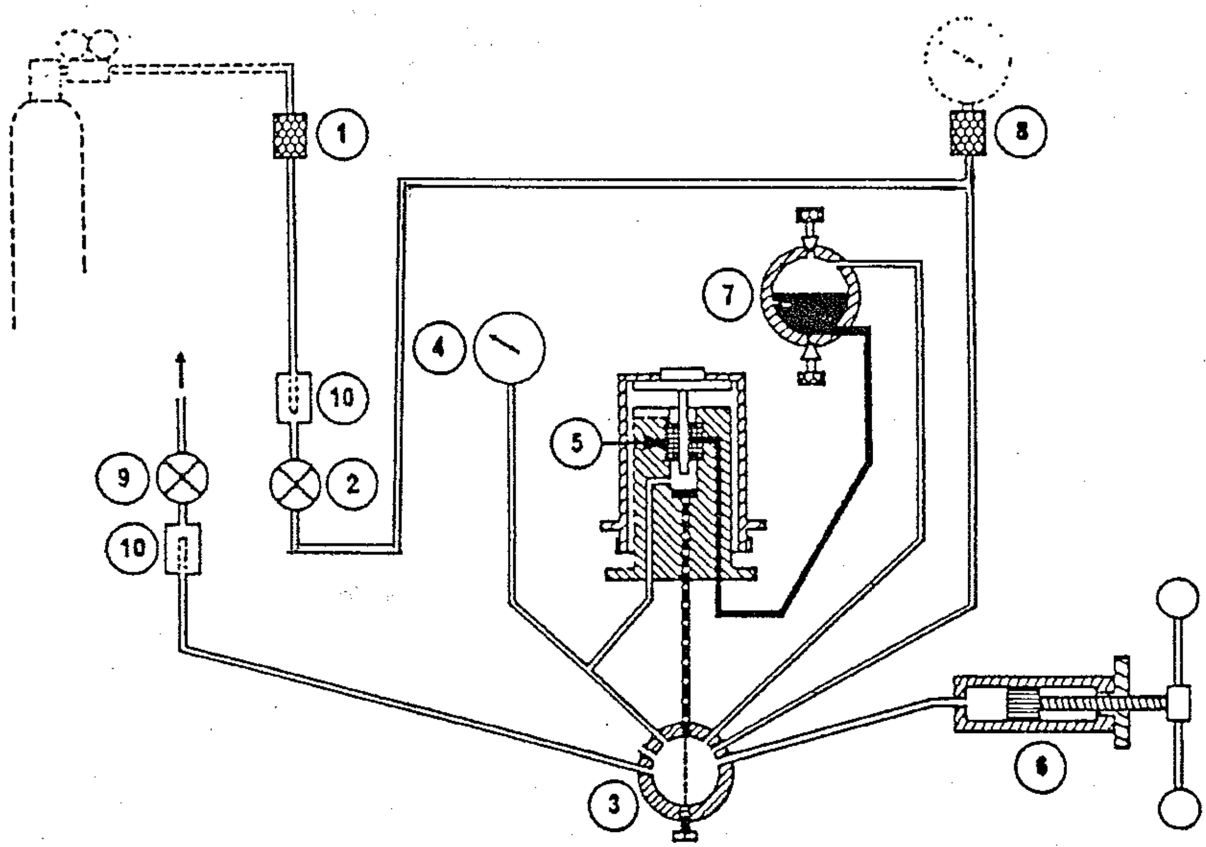
SYMPTOM	***POSSIBLE CAUSE***	***SOLUTION***
• Poor piston mobility	• Dirty piston-cylinder	• Remove and clean the piston-cylinder (see Section 3.2).
• Piston does not rotate	• Bad connection of the motor power supply cable	• Check motor cable.
	• Blown fuse	• Replace fuse (see Section 2.3).
	• Slip or deterioration of the drive belt	• Reinstall or replace drive belt. (see Section 5.3)
	• Burned out motor	• Replace electrical assembly (See Section 2.3).
• Aberrant measurements		• Purge lubrication system of air and standard for spent oil (see Section 3)
• Poor pressure stability	• Leak in pneumatic circuit. Isolate standard from test circuit to check standard for leaks. If leak is not in standard check test circuit. If leak is in standard check as follows:	
• External leak (visible)	• Clarification chamber drain-cock	Tighten if necessary.
	• "Gas Pressure" connecting head	•Replace O-ring assembly.
	• Mounting post	• The oil run-off cup fills rapidly. The two R-13 O-rings of the mounting post must be changed (see Section 5).
	• Gland nut in internal circuitry	• Tighten with system at zero pressure.
	• Exhaust valve	• Gas omitted from exhaust port, replace valve (see Section 2)
• Internal leak (not visible)	• Piston rises when system pressure is less than supply pressure and piston falls when system pressure is greater than supply pressure. Replace valve (see Section 2).	

NOTE: Manufacturer's reference numbers of the sub-assemblies are given in Section 2.2.

(User Notes)

CHAPTER 7 - SCHEMATIC

SYSTEM SCHEMATIC



1) "Gas Admission" Connecting Head
2) "Gas Admission" Valve
3) Sump
4) Indicating Gauge
5) Piston-Cylinder Mounting Post
6) Variable Volume
7) Visible Level Reservoir
8) "Gas Pressure" Connecting Head
9) "Gas Exhaust" Valve
10) Filters

(User Notes)

ANNEXES

- Values of the Correction Factor C_g
- Temperature Correction
- Temperature Correction
- Pressure Conversion Factors
- DH 400 High Pressure Flexible Tubes
- Spinelf 5 Data Sheet
- Krytox Material Data Sheet

VALUES OF THE CORRECTION FACTOR C_g AS A FUNCTION OF LOCAL GRAVITY

$$C_g = \frac{g_L}{g_M}$$

g_L : local gravity

g_M : standard gravity = 9.80665 m/s^2

g_L (m/s^2)	C_g
9.7800	0.99728
05	33
9.7810	0.99738
15	44
9.7820	0.99749
25	54
9.7830	0.99759
35	64
9.7840	0.99769
45	74
9.7850	0.99779
55	84
9.7860	0.99789
65	95
9.7870	0.99800
75	05
9.7880	0.99810
85	15
9.7890	0.99820
95	25
9.7900	0.99830
05	35
9.7910	0.99840
15	46
9.7920	0.99851
25	56

g_L (m/s^2)	C_g
9.7930	0.99861
35	66
9.7940	0.99871
45	76
9.7950	0.99881
55	86
9.7960	0.99891
65	96
9.7970	0.99902
75	07
9.7980	0.99912
85	17
9.7990	0.99922
95	27
9.8000	0.99932
05	37
9.8010	0.99942
15	47
9.8020	0.99953
25	58
9.8030	0.99963
35	68
9.8040	0.99973
45	78
9.8050	0.99983
55	88

g_L (m/s^2)	C_g
9.8060	0.99993
9.80665	1.00000
9.8070	1.00004
75	09
9.8080	1.00014
85	19
9.8090	1.00024
95	29
9.8100	1.00034
05	39
9.8110	1.00044
15	49
9.8120	1.00055
25	60
9.8130	1.00065
35	70
9.8140	1.00075
45	70
9.8150	1.00085
55	90
9.8160	1.00095
65	100
9.8170	1.00106
75	11
9.8180	1.00116
85	21

g_L (m/s^2)	C_g
9.8190	1.00126
95	31
9.8200	1.00136
05	41
9.8210	1.00146
15	51
9.8220	1.00157
25	62
9.8230	1.00167
35	72
9.8240	1.00177
45	82
9.8250	1.00187
55	92
9.8260	1.00197
65	202
9.8270	1.00208
75	13
9.8280	1.00218
85	23
9.8290	1.00228
95	33
9.8300	1.00238
05	43
9.8310	1.00248
15	53

TEMPERATURE CORRECTION

Piston And Cylinder In Tungsten Carbide

$$value \text{ of } C_\theta = 1-(\alpha_P+\alpha_C)(\theta-20) \qquad \alpha_P+\alpha_C = 9x10^{-6}{}^{\circ}C^{-1}$$

(°C)	C_θ
5	1.00014
6	1.00013
7	1.00012
8	1.00011
9	1.00010
10	1.00009
11	1.00008
12	1.00007
13	1.00006
14	1.00005
15	1.00004
16	1.00004
17	1.00003
18	1.00002
19	1.00001

(°C)	C_θ
20	1.00000
21	0.99999
22	0.99998
23	0.99997
24	0.99996
25	0.99996
26	0.99995
27	0.99994
28	0.99993
29	0.99992
30	0.99991
31	0.99990
32	0.99989
33	0.99988
34	0.99987

(°C)	C_θ
35	0.99986
36	0.99986
37	0.99985
38	0.99984
39	0.99983
40	0.99982
41	0.99981
42	0.99980
43	0.99979
44	0.99978
45	0.99978
46	0.99977
47	0.99976
48	0.99975
49	0.99974

TEMPERATURE CORRECTION

Piston In Steel And Cylinder In Tungsten Carbide

$$C_\theta = 1 - (\alpha_P + \alpha_C)(\theta - 20)$$

α_P : Thermal expansivity of steel = 1.05 x 10^{-5} [°C^{-1}]
α_C : Thermal expansivity of tungsten carbide = 4.50 x 10^{-6} [°C^{-1}]
θ : Temperature of the piston cylinder [°C]

(°C)	C_θ
5	1.00023
6	1.00021
7	1.00020
8	1.00018
9	1.00017
10	1.00015
11	1.00014
12	1.00012
13	1.00011
14	1.00009
15	1.00008
16	1.00006
17	1.00005
18	1.00003
19	1.00002

(°C)	C_θ
20	1.00000
21	0.99999
22	0.99997
23	0.99996
24	0.99994
25	0.99993
26	0.99991
27	0.99990
28	0.99988
29	0.99987
30	0.99985
31	0.99984
32	0.99982
33	0.99981
34	0.99979

(°C)	C_θ
35	0.99978
36	0.99976
37	0.99975
38	0.99973
39	0.99972
40	0.99970
41	0.99969
42	0.99967
43	0.99966
44	0.99964
45	0.99963
46	0.99961
47	0.99960
48	0.99958
49	0.99957

PRESSURE UNIT CONVERSIONS

	Pa (N/m²)	bar	psi (1)	kg/cm² (1)	mm Hg (torr) (1)(2)	in Hg (1)(2)	m H_2O (1)(3)	in H_2O (1)(3)
1 Pa (N/m²) =	1	1.000000 x 10^{-5}	1.450377 x 10^{-4}	1.019716 x 10^{-5}	7.500627 x 10^{-3}	2.953003 x 10^{-4}	1.019716 x 10^{-4}	4.014613 x 10^{-3}
1 bar =	1.000000 x 10^{-5}	1	1.450377 x 10	1.019716	7.500627 x 10^{2}	2.953003 x 10	1.019716 x 10	4.014613 x 10^{2}
(1) 1 psi =	6.894757 x 10^{3}	6.894757 x 10^{-2}	1	7.030696 x 10^{-2}	5.171500 x 10	2.036024	7.030696 x 10^{-1}	2.767990 x 10
(1) 1 kg/cm² =	9.806650 x 10^{-4}	9.806650 x 10^{-1}	1.422334 x 10	1	7.355602 x 10^{2}	2.895906 x 10	1.000000 x 10	3.937008 x 10^{2}
(1)(2) 1 mm Hg (torr) =	1.333222 x 10^{2}	1.333222 x 10^{-3}	1.933675 x 10^{-2}	1.359508 x 10^{-3}	1	3.937008 x 10^{-2}	1.359508 x 10^{-2}	5.352394 x 10^{-1}
(1)(2) 1 in Hg =	3.386384 x 10^{3}	3.386384 x 10^{-2}	4.911534 x 10^{-1}	3.453150 x 10^{-2}	2.540000 x 10	1	3.453150 x 10^{-1}	1.359508 x 10
(1)(3) 1 m H_2O =	9.806650 x 10^{3}	9.806650 x 10^{-2}	1.422334	1.000000 x 10^{-1}	7.355602 x 10	2.895906	1	3.937008 x 10
(1)(3) 1 in H_2O =	2.490889 x 10^{2}	2.490899 x 10^{-3}	3.612729 x 10^{-2}	2.540000 x 10^{-3}	1.868323	7.355602 x 10^{-2}	2.540000 x 10^{-2}	1

(1) Normal gravity: $g_n = 9.80665\ m/s^2$

(2) Density of mercury at 0°C and standard atmospheric pressure (101325 Pa): $Hg = 1.359508 \times 10^4\ kg/m^3$

(3) Density of water at 4°C and standard atmospheric pressure (101325 Pa): $H_2O = 1.000000 \times 10^3\ kg/m^3$

(User Notes)