PG7307™

Controlled Clearance Piston Gauge

Operation and Maintenance Manual

(Use with PG7000 Operation and Maintenance Manual)

High pressure liquids and gases are potentially hazardous. Energy stored in these liquids and gases can be released unexpectedly and with extreme force. High pressure systems should be assembled and operated only by personnel who have been instructed in proper safety practices.

Document No. 550127-01
070918
Printed in the USA.

TABLE OF CONTENTS

TABLES

FIGURES

ABOUT THIS MANUAL

This manual is designed to be used in conjunction with the PG7000 Piston Gauges Operation and Maintenance Manual, to operate a PG7307 Piston Gauge.

PG7307 is similar in conception and features to a PG7302 piston gauge. PG7307 differs in that it includes provisions for the application of an independent controlled clearance pressure to the outside surface of the cylinder. This includes differences in the piston-cylinder module and the mounting post. This manual covers the aspects of PG7307 that are different from PG7302.

To operate a PG7307, use the PG7000 Operation and Maintenance Manual and follow the instructions and information applying to PG7302. Refer to this manual for details on the PG7307 piston-cylinder mounting post and piston-cylinder modules and the use of controlled clearance pressure.

Manual Conventions

(CAUTION) is used in throughout the manual to identify user warnings and cautions.

(NOTE) is used throughout the manual to identify operating and applications advice and additional explanations.

[ ] indicates direct function keys (e.g., **[RANGE]**).
< > indicates PG7000 screen displays (e.g., **<1yes>**).

NOTES

1. INTRODUCTION

1.1 PRODUCT OVERVIEW

PG7307 is a special model in the PG7000 line of piston gauges. PG7307 is identical to PG7302 except for its piston-cylinder modules and mounting post.

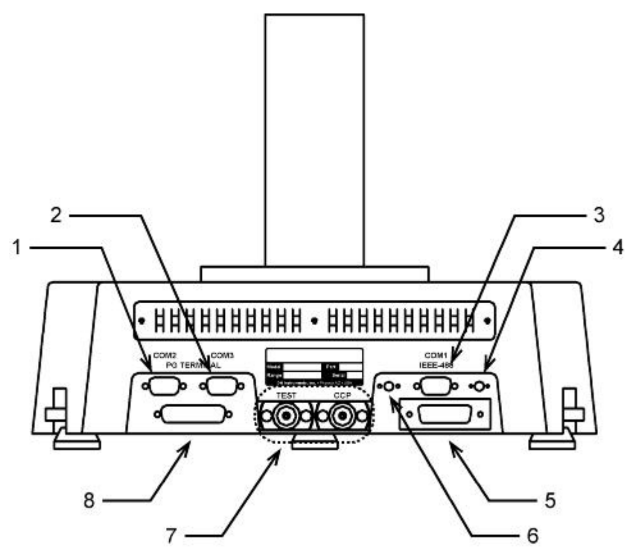
PG7307 is designed to allow an independent controlled clearance pressure (CCP) to be applied to the outside surface of the cylinder. The controlled clearance pressure is used to alter the pressure deformation coefficient of the piston-cylinder to study the piston-cylinder's elastic deformation with pressure. Relative to PG7302, PG7307 has different piston-cylinder modules that can only be mounted in the PG7307 mounting post. The PG7307 mounting post includes a passage for application of the independent controlled clearance pressure and there is a connection on the rear of the platform for the controlled clearance pressure source.

PG7307 is available on a limited basis and, generally, is only offered for use in national measurement institutes or other laboratories performing fundamental research in pressure metrology.

This manual was intended to be used as a supplement to the PG7000 Operation and Maintenance Manual. PG7307 is identical to PG7302 except for its piston-cylinder modules and mounting post. To operate a PG7307, use the PG7000 Operation and Maintenance Manual and the information on PG7302 referring to this manual for PG7307 piston-cylinder module mounting post and controlled clearance pressure information.

1.2 PLATFORM REAR PANEL

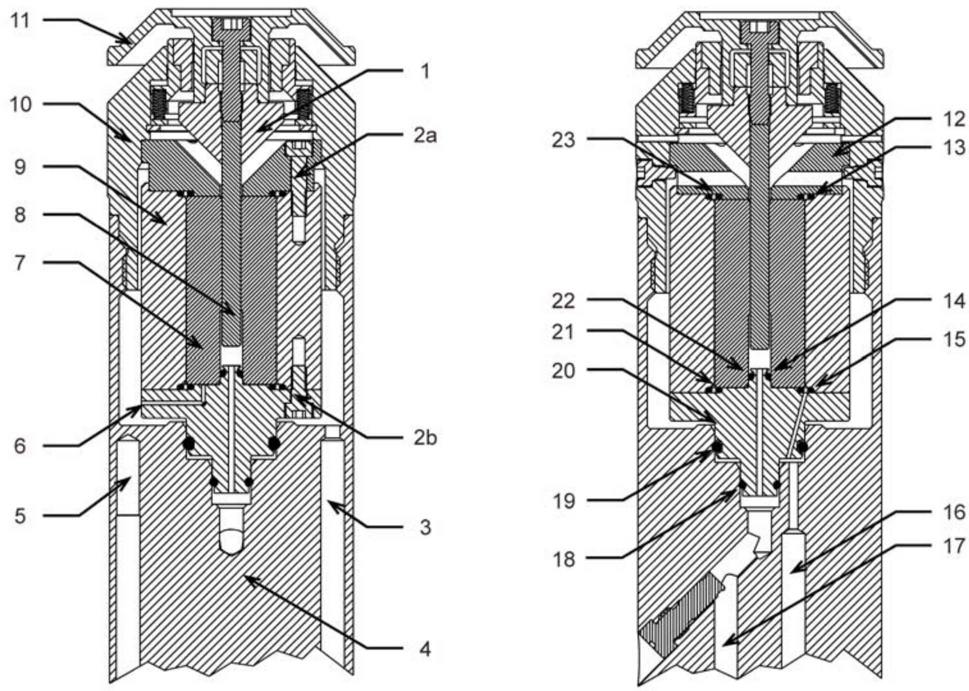
The PG7307 Platform rear panel provides the connection to the PG Terminal, remote communication connections, the measured pressure and controlled clearance pressure connection ports.



1. COM2 (RS232) - External Barometer and Pass Through Communications
2. COM3 (RS232) - Automated Pressure Generation/Control Component
3. COM1 (RS232) - Remote Host Communications
4. Ambient Temperature Sensor
5. IEEE-488 - Remote Host Communications
6. Ambient Relative Humidity Sensor
7. Pressure Ports:
   TEST Port: DH500
   CCP Port: DH500
8. PG7000 Terminal Port

Figure 1. PG7307 Platform Rear Panel

1.3 MOUNTING POST AND PISTON-CYLINDER MODULE SCHEMATIC



1. Piston Head
2. Flange Screws (2 ea)
3. Oil Run Off Passage
4. Mounting Post
5. Platinum Resistance Thermometer Mounting Hole
6. Weep Hole
7. Cylinder (tungsten carbide)
8. Piston (tungsten carbide)
9. Cylinder Sleeve
10. Module Retaining Nut
11. Piston Cap
12. Upper Sleeve Flange
13. Controlled Clearance Pressure Sleeve O-Ring
14. Cylinder Counter Bore
15. Controlled Clearance Pressure Sleeve O-Ring
16. Controlled Clearance Pressure Supply
17. Measured Pressure Supply
18. Measured Pressure Mounting Post O-Ring
19. Controlled Clearance Pressure Mounting Post O-Ring
20. Lower Sleeve Flange
21. Controlled Clearance Pressure Cylinder O-Ring, Lower Sleeve Flange (and Anti-extrusion Ring for 500 kPa, 1 Mpa and 2 Mpa P-C Modules)
22. Measured Pressure Cylinder O-Ring
23. Controlled Clearance Pressure Cylinder O-Ring, Upper Sleeve Flange

Figure 2. PG7307 Mounting Post and Piston-Cylinder Module Schematic

1.4 SPECIFICATIONS

1.4.1 GENERAL SPECIFICATIONS

Specifications below are specific to PG7307. All other specifications are identical to PG7000 specifications found in the PG7000 Operation and Maintenance Manual (P/N 550099).

Weight *Instrument platform with no mass loaded.*	13 kg (29 lb)	
Overall Pressure Range	100 kPa to 200 MPa (14.5 to 30 000 psi)	
Normal Operating Medium	Di-2 EthylHexyl Sebacate	
Maximum Mass Load	100 kg, while not exceeding 200 MPa (30 000 psi)	
Pressure Connections	Test Port:	DH500
	Controlled Clearance Pressure (CCP) Port:	DH500

DH500 is a gland and collar type fitting for 1/4 in. (6 mm) coned and left hand threaded tubes equivalent to AE F250C, HIP HF4, etc.

1.4.2 PISTON-CYLINDER MODULES

Oil operated, controlled clearance, piston-cylinder module characteristics.

For all modules, pressure deformation is near zero with a controlled clearance pressure of 20 to 25 % of the measured pressure.

PC-7307-100 (Kn = 100 kPa/kg)

Operation	Oil operated, oil lubricated
Piston Material	Tungsten carbide
Cylinder Material	Tungsten carbide
Nominal Diameter	11.2 mm
Nominal Area	98.1 mm^2
Mounting System	Simple free deformation with controlled clearance feature
Typical Drop Rate (50 kg, zero CCP)	0.04 mm/min
Nominal pressure deformation (zero CCP)	1.2×10^{-6} MPa^{-1}

PC-7300-200 (Kn = 200 kPa/kg)

Operation	Oil operated, oil lubricated
Piston Material	Tungsten carbide
Cylinder Material	Tungsten carbide
Nominal Diameter	7.9 mm
Nominal Area	49.0 mm^2
Mounting System	Simple free deformation with controlled clearance feature
Typical Drop Rate (50 kg, zero CCP)	0.08 mm/min
Nominal pressure deformation (zero CCP)	8.9×10^{-7} MPa^{-1}

PC-7300-500 (Kn = 500 kPa/kg)

Operation	Oil operated, oil lubricated
Piston Material	Tungsten carbide
Cylinder Material	Tungsten carbide
Nominal Diameter	5.0 mm
Nominal Area	19.6 mm^2
Mounting System	Simple free deformation with controlled clearance feature
Typical Drop Rate (50 kg, zero CCP)	0.25 mm/min
Nominal pressure deformation (zero CCP)	7.5×10^{-7} MPa^{-1}

PC-7300-1 (Kn = 1 MPa/kg)

Operation	Oil operated, oil lubricated
Piston Material	Tungsten carbide
Cylinder Material	Tungsten carbide
Nominal Diameter	3.5 mm
Nominal Area	9.8 mm^2
Mounting System	Simple free deformation with controlled clearance feature
Typical Drop Rate (50 kg, zero CCP)	0.50 mm/min
Nominal pressure deformation (zero CCP)	7.2×10^{-7} MPa^{-1}

PC-7300-2 (Kn = 2 MPa/kg)

Operation	Oil operated, oil lubricated
Piston Material	Tungsten carbide
Cylinder Material	Tungsten carbide
Nominal Diameter	2.5 mm
Nominal Area	4.9 mm^2
Mounting System	Simple free deformation with controlled clearance feature
Typical Drop Rate (50 kg, zero CCP)	1.00 mm/min
Nominal pressure deformation (zero CCP)	7.1×10^{-7} MPa^{-1}

2. INSTALLATION

2.1 UNPACKING AND INSPECTION

2.1.1 INSPECTING CONTENTS

Check that all items are present and have no visible damage.

2.1.1.1 PG7307 PLATFORM

Table 1. PG7307 Parts List

DESCRIPTION	PG7307 P/N 401758 MOTORIZED ROTATION NON-CE	PG7307 P/N 401758-CE MOTORIZED ROTATION CE	PG7307 P/N 401757 NON-MOTORIZED ROTATION NON-CE	PG7307 P/N 401757-CE NON-MOTORIZED ROTATION CE
Platform	401760	401760-CE	401759	401759-CE
Mass Bell	402098			
Terminal	401284			
PG Terminal to Platform Cable Non-CE (DB25M -DB25F, ≈ 1.8 meters) CE (DB25M - DB25F, ≈ 1.5 meters)	102227	102227-CE	102227	102227-CE
Power Cable	100770 (Black)	100770-CE (Gray)	100770 (Black)	100770-CE (Gray)
Accessory Kit	401134			
NIP, SS, DH200, 2.75 in.	100204			
ADPT, SS, DH200 F x 2 NPT F	100299			
O-ring, Buna 2-242 (2 ea.)	101976			
Storage Cover, 7600 Type	102132			
Allen Wrench, 2.5 mm	102257			
Allen Wrench, 3 mm	102168			
Allen Wrench, 5 mm	102262			
Spanner Wrench (Metrological)	122568			
Wrench, 5/8 in.	103044			
Collar, SS, DH500	101201			
Krytox® GPL205/6 0.5 oz	102496			
Gift Kit with Gloves	400511			
Documentation Calibration Report (PG) Calibration Report (Mass Bell) Technical Data PG7000 Operation & Maintenance Manual PG7307 Operation & Maintenance Manual Documentation CD	 550100 550100 550101 550099 550127 102987			

2.1.1.2 PISTON-CYLINDER MODULE

Table 2. PG7307 Piston-Cylinder Modules Parts List

	PC-7307-100 100 kPa/kg	**PC-7300-200 200 kPa/kg**	**PC-7300-500 500 kPa/kg**	**PC-7300-1 1 MPa/kg**	**PC-7300-2 2 MPa/kg**
Piston-Cylinder Kit	401761	401762	401763	401764	401765
Piston-Cylinder Module	401851	401852	401853	401854	401855
Hermetic PVC Bullet Case	401850	401850	401850	401850	401850
Accessory Kit	401818	401819	401826	401826	401826
O-rings	101675 (2 ea) 101972 (2 ea) 102109 (1 ea) 101294 (2 ea)	101675 (2 ea) 101972 (2 ea) 102109 (1 ea) 101294 (1 ea) 101206 (1 ea)	101675 (2 ea) 101972 (2 ea) 102109 (1 ea) 101294 (1 ea) 102296 (1 ea)	101675 (2 ea) 101972 (2 ea) 102109 (1 ea) 101294 (1 ea) 102296 (1 ea)	101675 (2 ea) 101972 (2 ea) 102109 (1 ea) 101294 (1 ea) 102296 (1 ea)
Anti-Extrusion Ring	N/A	N/A	123537	123537	123537
Calibration Report	550100	550100	550100	550100	550100

2.2 INITIAL SETUP

2.2.1 CCP PRESSURE CONNECTION

The pressure connection labeled CCP is for the application of a *controlled clearance pressure* to the outside of the cylinder (see Section 3.1).

2.2.2 INSTALLING AND REMOVING THE PISTON-CYLINDER MODULE

This piston-cylinder module is installed and removed from the piston gauge platform in the same manner as PG7302 and other PG7000 piston-cylinder modules. See the PG7000 Operation and Maintenance Manual.

3. OPERATION

3.1 CONTROLLED CLEARANCE PRESSURE (CCP)

❍ PRINCIPLE

PG7307 allows an independent pressure to be applied to the total outside length of the cylinder. The purpose of this feature is to apply a counter-force to the outside of the cylinder in order to vary the size of the gap between the piston and the cylinder. The ability to predictably vary the size of the gap between the piston and the cylinder can be useful in analyzing piston-cylinder elastic deformation.

The controlled clearance pressure is introduced through the CCP port on the back of the PG7307 platform. The pressure is applied to the cylinder through the mounting post to a separate circuit in the piston-cylinder module (see Figure 2).

See the publication in the Appendix section of this manual, “A New Oil Operated Controlled Clearance Piston Gauge for Operation to 200 MPa” for additional information on PG7307 principles of design and use.

❍ OPERATION

The recommended range of CCP for the experimental study of the pressure deformation coefficient is from zero to 50 % of the measured pressure. Since the CCP resulting in zero deformation coefficient is about 25 % of the measured pressure, a CCP range of zero to 50 % of the measured pressure allows positive and negative deformation values symmetric around zero to be obtained.

⚠ By design, the maximum controlled clearance pressure (CCP) used in PG7307 is the pressure corresponding to a 100 kg mass load on the piston or 100 MPa, whichever is smaller. Exceeding these limits can damage the piston-cylinder. The recommended range of CCP is from zero to 50 % of the measured pressure.

⚠ Always increase the measured pressure before applying the CCP.

Always decrease the CCP before removing the measured pressure.

For example, when starting from zero measured pressure, always generate the measured pressure first and then apply the CCP. When going back to zero measured pressure, always vent the CCP first, before venting the measured pressure.

NOTES

4. MAINTENANCE, ADJUSTMENTS AND CALIBRATION

4.1 DISASSEMBLY AND REASSEMBLY OF CONTROLLED CLEARANCE OIL OPERATED PISTON-CYLINDER ASSEMBLIES (PG7307)

The PG7000 piston-cylinder module design affords maximum protection to the piston-cylinder element ensuring that it is protected during routine piston-cylinder handling. Cleaning the piston-cylinder requires disassembly of the module and exposure of the piston-cylinder to possible damage. These risks include damage to the critical working surfaces for all piston-cylinder sizes and chipping or breaking, especially for small diameter piston-cylinders. Only qualified personnel should undertake piston-cylinder disassembly, cleaning and reassembly. The instructions and recommendations contained in this manual should be followed carefully throughout the operation.

NEVER touch the lapped surfaces (polished appearance) of the piston or cylinder with your bare hands. Body oils and acids can permanently etch the surfaces.

In normal use, always maintain PG7307 oil piston-cylinders vertical with the O-ring assembly down. Do not invert the assembly and allow oil to run up the piston head into the adjustment mass and cap. Oil contamination of the piston head and cap changes the total mass of the piston assembly and could be significant at low mass loads. If oil contaminates the adjustment mass and cap, disassemble the module and clean it (see PG7000 Operation and Maintenance Manual).

To assemble and disassemble a PG7307 piston cylinder module, proceed as follows:

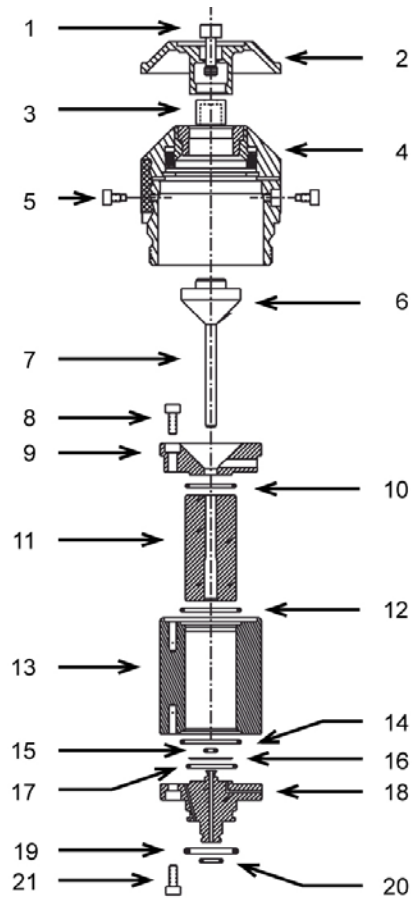


Figure 3. Oil Piston-Cylinder Module (Exploded View)

❶ Screw the piston-cylinder module into the base of its bullet case (PVC shipping and storage case) and place the base and module on a clean stable surface with the piston cap (2) up.

❷ Using a 3 mm Allen tool, loosen the two socket head sleeve retaining screws (5) from the opposing sides of the main module housing (4).

In reassembly, after the two sleeve retaining screws (5) are installed, sleeve assembly (9+13+18) must still have a small amount of freedom to move and rotate within the main module housing (4).

❸ While firmly holding down the cap (2), use a 5 mm Allen tool, to loosen the socket head cap retaining screw (1). Turning the screw pushes the piston head (6) straight out of the piston cap (2) ensuring that no sideways torque is applied to the piston (7). The cap retaining screw will not fully disengage from the piston cap due to the adjustment mass (3). Gently remove the cap and screw from the assembly. Use caution to be sure the piston head is out of the cap so as NOT to apply torque to the piston (7) when removing the cap.

When installing the piston cap during reassembly, remember to reinstall the adjustment mass (3). Take great care to slip the piston cap (2) straight onto the piston head (6) and not to apply torque to the piston (7).

❹ Unscrew the main module housing (4) from the bullet case leaving the piston-cylinder and sleeve assembly (9+13+18) behind in the bullet case base. Carefully reinstall the piston cap (2) onto the piston head (6) taking care not to apply sideways torque on the piston (7). Using the cap as a handle, slide the piston **straight** out of the cylinder.

Remove the cylinder and sleeve assembly (8 + 9 + 13) from the bullet case base. Turn over the assembly and place it on the sturdy surface with the O-ring assembly (18) up.

Stop here if you are doing a simple cleaning of the piston-cylinder. The cylinder (11) can be cleaned within the sleeve assembly (9+13+18) by flushing with clean oil. The O-ring assembly (18) is NOT intended to be regularly disassembled. Do not proceed with the next step of disassembly unless it is suspected that a repair is required. Do not proceed with the next step of disassembly if you do NOT have a new set of O-rings (10, 12, 14, 15, 17) and anti-extrusion ring (16) to use in reassembly. It is imperative that new parts be used in reassembly (not all modules have an anti-extrusion and all the O-rings (see Table 2)).

❻ Using a 2 mm Allen tool, loosen the two O-ring assembly retaining screws (21). Lift off the O-ring assembly (18) and the retaining screws. Remove O-rings (14, 17) and the anti-extrusion ring (16) (PC-7307-200 and -100 do NOT have an anti-extrusion ring).

In reassembly use new O-rings and anti-extrusion ring only and take special care to center the anti-extrusion ring on the shoulder of part (18).

❼ Holding the cylinder (11) in the open end of the cylinder sleeve (13), turn the cylinder sleeve over and allow the cylinder to gently slide out. Remove O-ring (10). Using a 3 mm Allen tool, loosen the cover retaining screws (8). Remove the cover (9) and remove the O-ring (12).

In reassembly use new O-rings. The end of the cylinder marked with the serial number must be upwards (towards the cover (9)).

The orientation of the piston on the cylinder is important. The end of the cylinder that is marked with the serial number should be upwards (against the sleeve cover (9)). Installing the cylinder with the wrong orientation may lead to out of tolerance measurements.

5. TROUBLESHOOTING

5.1 OVERVIEW

Identify the symptom or unexpected behavior you are observing from the **SYMPTOM** list below. A **PROBABLE CAUSE** is provided and a **SOLUTION** is proposed including references to manual sections that provide information that may be of assistance. Table 3 concerns troubleshooting issues for the PG7307 only. See the PG7000 Operation and Maintenance Manual for the complete PG7000 troubleshooting checklist.

Table 3. PG7307 Troubleshooting Checklist

SYMPTOM	PROBABLE CAUSE	SOLUTION
Piston lacks sensitivity/mobility. Piston rotation rate decreases too rapidly.	Controlled clearance pressure too high relative to measured pressure is causing gap between piston and cylinder to be too small.	Reduce controlled clearance pressure and/or increase measured pressure. (3.1)
Controlled clearance pressure will not stabilize and decreases rapidly.	Leak in controlled clearance pressure circuit of piston-cylinder module.	Remove module and replace O-ring (19). If problem persists, disassemble the module and replace O-rings (12, 14). (4.1)
Controlled clearance pressure will not stabilize and increases rapidly.	Leak from the measured pressure circuit to the controlled clearance pressure circuit.	Remove module and replace O-ring (20). If problem persists, disassemble and change O-rings (10, 17). (4.1)

NOTES

6. WARRANTY STATEMENT

Except to the extent limited or otherwise provided herein, **DH Instruments, a Fluke Company** (**DHI**) warrants for one year from purchase, each new product sold by it or one of its authorized distributors, only against defects in workmanship and/or materials under normal service and use. Products which have been changed or altered in any manner from their original design, or which are improperly or defectively installed, serviced or used are not covered by this warranty.

DHI and any of its authorized service providers' obligations with respect to this warranty are limited to the repair or replacement of defective products after their inspection and verification of such defects. All products to be considered for repair or replacement are to be returned to **DHI**, or its authorized service provider, freight prepaid, after receiving authorization from **DHI** or its authorized service provider. The buyer assumes all liability vis-à-vis third parties in respect of its acts or omissions involving use of the products. In no event shall **DHI** be liable to purchaser for any unforeseeable or indirect damage, it being expressly stated that, for the purpose of this warranty, such indirect damage includes, but is not limited to, loss of production, profits, revenue, or goodwill, even if **DHI** has been advised of the possibility thereof, and regardless of whether such products are used individually or as components in other products.

Items returned to **DHI** under warranty claim but determined to not have a defect covered under warranty or to not have a defect at all are subject to an evaluation and shipping charge as well as applicable repair and/or calibration costs.

The provisions of this warranty and limitation may not be modified in any respect except in writing signed by a duly authorized officer of **DHI**.

The above warranty and the obligations and liability of **DHI** and its authorized service providers exclude any other warranties or liabilities of any kind.

Table 4. DHI Authorized Service Providers

DH INSTRUMENTS, A FLUKE COMPANY AUTHORIZED SERVICE PROVIDERS			
COMPANY	**ADDRESS**	**TELEPHONE, FAX & EMAIL**	**NORMAL SUPPORT REGION**
DH Instruments, a Fluke Company	4765 East Beautiful Lane Phoenix AZ 85044-5318 USA	Tel 602.431.9100 Fax 602.431.9559 msearle@dhinstruments.com	Worldwide
Minerva I.P.&M. B.V.	Handelsweg 13 Postbus 76-1270 AB Huizen NETHERLANDS	Tel 31/35.52.54.997 Fax 31/35.52.64.560 info@minervaipm.com	European Union
Nippon CalService, Inc.	2-9-1 Sengen, Tsukuba-Shi Ibaraki Prefecture 305 JAPAN	Tel 0298-55-8778 Fax 0298-55-8700 tohte@ohtegiken.co.jp	Japan/Asia
DH Products Technical Service Division	National Institute of Metrology Heat Division Pressure & Vacuum Lab NO. 18, Bei San Huan Donglu Beijing 100013 PR CHINA	Tel 010-64291994 ext 5 Tel 010-64218637 ext 5 Fax 010-64218703 cxcen@mx.cei.gov.cn	Peoples Republic of China

NOTES

APPENDIX

A NEW OIL OPERATED CONTROLLED CLEARANCE PISTON GAUGE FOR OPERATION TO 200 MPA

Pierre Delajoud, Martin Girard
DH Instruments, a Fluke Company
4765 East Beautiful Lane
Phoenix, AZ 85044-5318 – USA

Abstract

An oil operated, controlled clearance piston gauge has been developed for the purpose of experimentally determining the pressure deformation coefficient of a piston-cylinder by varying an independent pressure around the cylinder. The gauge is obtained by designing a new mounting post for a commercially available piston gauge platform. The piston-cylinders, also commercially produced in diameters from 11.2 to 2.5 mm, are integrated into interchangeable modules which include dedicated mounting components. A standard 100 kg mass set gives ranges from 10 to 200 MPa. The piston-cylinders can be operated with a controlled clearance pressure or without, in which case they behave as in a conventional free deformation piston gauge. The piston gauge is well suited for intercomparisons as it is easily transportable and accepts masses that are already present in many metrology laboratories.

1. Introduction

In recent years, major efforts have been devoted to reducing the uncertainty in effective area of piston gauges used as primary pressure standards. The main focus of these efforts has been on the effective area of gas operated piston-cylinders in the relatively low range from a less than one to several atmospheres. In this range, the dominant uncertainties are those associated with knowledge of the exact physical dimensions of the piston and the cylinder and the behavior of gas in the gap between the two. Over the past 10 to 15 years, the application of improved dimensional measurement capabilities to large diameter piston-cylinders has allowed the estimated uncertainty in effective area for piston gauges used as primary standards to be reduced by nearly an order of magnitude. Direct comparisons with manometers, another technique that derives pressure directly from the base units of mass, length and time, has supported the reduced uncertainty estimates.

The situation for higher pressures is quite different. As the use of manometers above a few atmospheres is not practical, the piston gauge is the only primary standard available. Effective area values determined for large diameter, low pressure piston-cylinders can be transferred to smaller diameter higher pressure piston-cylinders with very little added uncertainty. However, as pressure increases, the uncertainty in effective area due to the uncertainty in change in effective area with pressure becomes significant. A typical tungsten carbide piston-cylinder in a simple, free deformation mounting system has a theoretical pressure deformation coefficient of 7.9 x 10-7 MPa-1[1]. This leads to a change in effective area of 1.6 x 10-4 at 200 MPa. If the uncertainty in the deformation coefficient is estimated to be + 1 x 10-1, the resulting uncertainty in effective area at 200 MPa due to uncertainty in the deformation coefficient is + 1.6 x 10-5, very large relative to the starting uncertainty of less than + 1 x 10-5 that is achievable for the piston-cylinder effective area at low pressure.

The uncertainty in effective area at high pressure due to uncertainty in the pressure deformation coefficient can be reduced by experimental determination of deformation with pressure. The techniques for determining deformation generally have in common the application of an independent pressure, often called controlled clearance pressure (ccp), to the outside surface of the cylinder. The force resulting from the ccp counteracts the deformation of the cylinder and adjusts the gap between the piston and the cylinder.

The elastic behavior of the piston-cylinder assembly in response to measured and controlled clearance pressure is evaluated experimentally in two ways. One is by crossfloat with a highly reproduceable "tare" piston gauge at various measured pressures. At each measured pressure, the ccp is changed while the measured pressure is held constant by the tare gauge. For each controlled clearance pressure, a new crossfloat equilibrium is precisely established by slight adjustment of the mass load on one of the gauges. The relative change in effective area with controlled clearance pressure, is equal to the relative change in mass load. Another means of evaluating the elastic behavior of the piston-cylinder is by measurement of oil flow through the piston-cylinder gap for different values of ccp. Several approaches for deriving the pressure deformation coefficient from these experimental methods have been developed and are well documented [2, 3, 4].

Piston gauges using a controlled clearance pressure have been produced commercially for many years. Though they are used to study piston-cylinder pressure deformation, their principle application and the focus of their design was to allow operation at very high pressure (> 500 MPa). In this case, the main function of the controlled clearance pressure was to limit the deformation of the cylinder in order to maintain acceptable piston drop rates and, with the introduction of tungsten carbide cylinders, to prevent breakage when the stresses induced by the measured pressure exceeded the tensile strength of the material. Most existing controlled clearance piston gauges have several shortcomings for use as primary standards. One of these is piston-cylinder mounting designs in which unintended stresses are caused by the measured pressure connection and/or in which pressure seals are located on the outside of the cylinder in a manner which results in unfavorable stress distribution. Another is that at the time the gauges were produced, the materials and machining techniques available did allow the quality of parts that can be produced today. In consequence, to operate properly, a larger starting gap was necessary. This resulted in a high gap to radius ratio and, in turn, high piston drop rate. High piston drop rate makes routine use awkward and hinders precise crossfloating and drop rate measurement. These problems are compounded by non-ideal geometry which causes effective area to change with piston position. Finally, existing controlled clearance gauges tend be very large and non-transportable, making direct intercomparisons between laboratories impractical.

DH Instruments, a Fluke Company, a manufacturer of high performance piston gauges, has introduced a new oil operated, controlled clearance piston gauge. The new piston gauge is specifically intended as a tool for determining the pressure deformation coefficient of piston-cylinders in the pressure range from 0.1 to 200 MPa. It is designed to maximize repeatability for given measured pressure and controlled clearance pressure values.

2. Overview of the Controlled Clearance Piston Gauge

Figure 1 – Oil Operated, Controlled Clearance Piston Gauge (PG7307)

The new controlled clearance piston gauge [Figure 1] is derived from the commercially available PG7302 oil operated piston gauge. Existing piston-cylinder sizes are used in a new piston-cylinder module with provision for application of the controlled clearance pressure to the outside of the cylinder. The proven mechanical design and extensive features of the existing PG7000 piston gauges are exploited by installing a new mounting post on the existing PG7000 platform. These features include on-board monitoring of ambient conditions, piston temperature, piston position and rotation rate. These are accessible both remotely and from a local display. The PG7000 mass loading bell is used assuring compatibility with existing DH Instruments PG7000, as well as Desgranges et Huot Type 5000 mass sets.

3. The Piston-Cylinder Modules

As with other PG7000 piston gauges, the piston-cylinder is associated with its own dedicated critical mounting components in a module [Figure 2]. The module is handled as integrated assembly, installed or removed from the piston gauge platform by threading it on and off the mounting post in a simple, repeatable process [Figure 3]. Thus, the piston-cylinder and all of

Figure 2 – Controlled Clearance Piston-Cylinder Module

the parts that influence its pressure deformation coefficient always remain together. By design, the seals between the module and the mounting post play no role in the pressure deformation of the piston-cylinder. The piston-cylinder modules accommodate existing piston-cylinder sizes (nominal diameter): 11.2, 7.9, 4.9, 3.5 and 2.5 mm. These give maximum pressure with a 100 kg

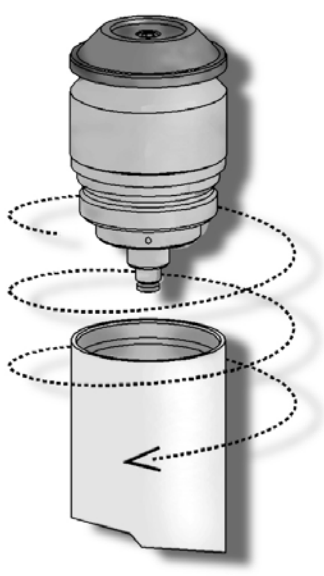


Figure 3 – Oil Piston-Cylinder Module Installation

mass load of 10, 20, 50, 100 and 200 MPa respectively. By using existing piston-cylinder sizes, the piston-cylinders benefit from the experience and size specific know how that come from producing them in significant quantities. All pistons and cylinders are made of tungsten carbide. Typical deviation from ideal cylindrical shape for the piston and the cylinder is equal to or better than ± 0.2 micrometer. The normal piston-cylinder gap size is from 0.6 to 1.2 micrometers. The specific size is determined by piston-cylinder diameter to optimize performance when operated with a controlled clearance pressure value that causes the deformation coefficient to be close to zero. However, the gap size can be adapted for other considerations, for example to allow the ccp to be as high as 100 % of the measured pressure.

The controlled clearance piston-cylinder module parts are designed to operate with controlled clearance pressure up to 100% of the measured pressure to a maximum of 100 MPa, assuming the piston-cylinder gap is sized to allow it. For the different piston-cylinder sizes, the cylinder dimensions and mounting system are such that a ccp of 20 to 25 % of the measured pressure results in a pressure deformation coefficient close to zero. The modules can also be operated in simple free deformation, i.e. with zero controlled clearance pressure. In free deformation, the theoretical pressure deformation coefficient of the 200 MPa (2.5 mm nominal diameter) piston-cylinder with a 100 kg load is 7.1 x 10-7 MPa-1, about 10 % less than the same piston-cylinder in a conventional free deformation module.

4. Design Comments and Considerations

Though the controlled clearance gauge uses the same nominal piston-cylinder diameters as those used in commercial free deformation piston gauges, in the controlled clearance application it was considered desirable to modify the design of the cylinder in order to further reduce end loading effects by minimizing constraints associated with boundaries between the cylinder and the mounting components [Figure 4] (all numerical references in this section refer to Figure 4). The length of the cylinder (4) is increased so that the measured pressure sealing O-ring (15) can be installed on an internal diameter that is slightly larger than the effective area diameter. This configuration almost completely eliminates any vertical force from the measured pressure on the cylinder.

The controlled clearance pressure is sealed near the peripheries of the top and bottom surfaces of the cylinder by two identical and symmetrically mounted O-rings (16, 17). The forces on the top and bottom of the cylinder resulting from the controlled clearance pressure cancel each other out resulting in a null vertical force value on the cylinder, regardless of the value of the controlled clearance pressure. This allows the upper portion of the cylinder to deform freely in the radial direction proportionally to the measured and controlled clearance pressures.

References

[1] A. Ooiwa, "Development of a Highly Stable Air Piston Pressure Gauge with Non-Rotational Piston-Cylinder System", in Proceedings of Flucome Tokyo ’85, 1985, pp. 959-964.

[2] A. Ooiwa, “Novel Nonrotational Piston Gauge with Weight Balance Mechanism for the Measurement of Small Differential Pressures”, Metrologia, Volume 30, No. 6, pp. 607-610, 1994.

[3] Model PR2003 Comparator, manufactured by Mettler Toledo GmbH, CH-8686, Greifensee, Switzerland.

[4] Model 698A S/N 95198220 manufactured by MKS Instruments, 6 Shattuck Rd., Andover, MA 01080, USA; property of Mittatekniikan Kesku, Center for Metrology and Accreditation, Lonnrotinkatu 37, FIN-00181 Helsinki, Finland.