

# PG7000™

## PISTON GAUGES

Reference Level Pressure Standards



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### INTRODUCTION...

The piston gauge's fundamental operating principle and excellent long term stability have made it an indispensable tool in high accuracy pressure metrology. As accuracy levels increase, quality assurance requirements intensify and automation spreads through the workplace, the piston gauge must evolve to continue to fill its essential role in the measurement system. **PG7000**, the first truly new, high end piston gauge introduced since the late 1970s, responds to this challenge.

**PG7000** development was undertaken with four main inter-related design objectives:

- **Deliver real improvements in fundamental metrological performance** to assure that today's — and tomorrow's — ever increasing accuracy requirements can be supported.
- **Integrate automated monitoring of environmental and instrument operating conditions with extensive on-board intelligence** to provide a modern stand alone instrument that outputs fully validated reference pressures, real time, through an intuitive operator interface.
- **Reduce — and when possible eliminate — the influence of the operator** on measurements to assure more consistent performance.
- **Improve piston gauge ergonomics** for greater operator satisfaction and increased productivity.



The PG7000 design objectives were pursued with the refinement of existing techniques, innovative new design, process improvements and the thorough application of today's digital and information processing technologies. The result is a coherent line of piston gauges that sets a new standard for both performance and usability, redefining the state of the art in high end pressure metrology.

The pages that follow describe the **PG7000** line.

**GENERAL FEATURES:** Pages 3 to 8 describe features that distinguish **PG7000s** from conventional piston gauges.

**PG PLATFORMS:** Pages 9 to 12 cover each **PG7000** platform:

- **PG7302** for oil operation.
- **PG7102** for gas operation without vacuum reference capability.
- **PG7601** for gas operation with vacuum reference capability.

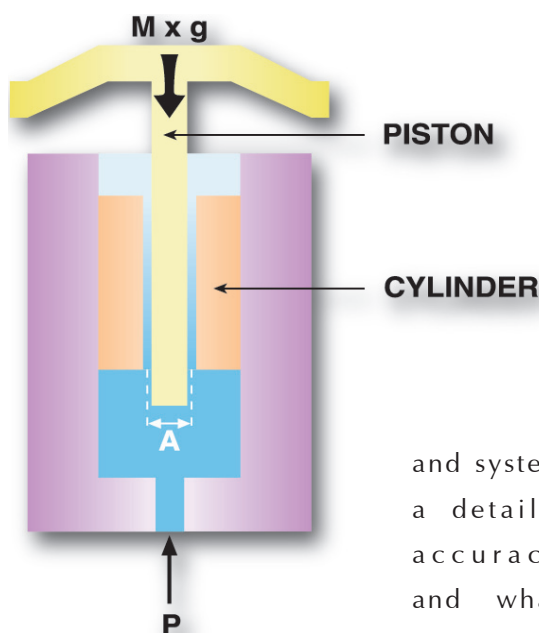
Information on how to configure a complete PG7000 system, including piston-cylinder module, mass set and pressure control accessories is provided here.

**PISTON-CYLINDER MODULES:** Pages 13 and 14 provide complete details on the piston-cylinder

modules available for use with **PG7000** platforms. Use the tables here to determine the best piston-cylinder and mass set combination to cover your pressure ranges.

**MASS SETS:** Pages 15 and 16 cover **PG7000's** masses with technical details and break downs of each mass set.

**SPECIFICATIONS:** Pages 17 and 18 provide complete specifications for **PG7000** piston gauges and systems. This includes a detailed definition of accuracy specifications and what they mean at **DHI**. Please read and



$$P = \frac{\sum_i M_i g_l \left(1 - \frac{\rho_a}{\rho_m}\right) + \pi D \tau}{A(T_r, P_r) [1 + (\alpha_p + \alpha_c)(T - T_r)] (1 + \lambda P)} - \rho_r g_l h$$

evaluate accuracy definitions carefully when comparing piston gauges.

Though you'll find that this catalog goes well beyond conventional commercial literature in its efforts to inform you... everything about **PG7000** cannot be included here. For additional **PG7000** assistance, or information on **DHI's** other pressure and flow calibration products and services, please contact **DHI** or your local representative. You can count on us to analyze your needs and objectively propose the best solutions to meet them.

## INTEGRATED PISTON-CYLINDER METROLOGICAL MODULES

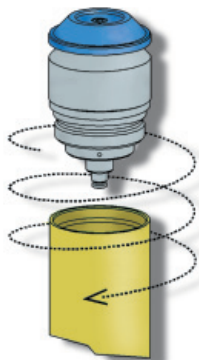
Each PG7000 piston-cylinder is an integrated metrological assembly that includes the critical piston-cylinder mounting components. To change piston-cylinders, the complete module is installed and removed from the piston gauge mounting post.



Interchangeable Piston-Cylinder Modules

All of the mechanical parts that affect piston-cylinder metrology are associated with the individual piston-cylinder rather than being common parts of the piston gauge platform. This unique design provides many practical and metrological benefits. These benefits include:

- Change ranges (piston-cylinders) in seconds, without using tools.
- Handle and interchange piston-cylinders without exposing critical surfaces to contamination.
- Protect the piston-cylinder from damage due to accidental shock or impact when handling.
- Improve measurement reproducibility by avoiding frequent assembly/disassembly of mounting components and assuring that each piston-cylinder is always used with the same mounting hardware, even when used in a different platform.



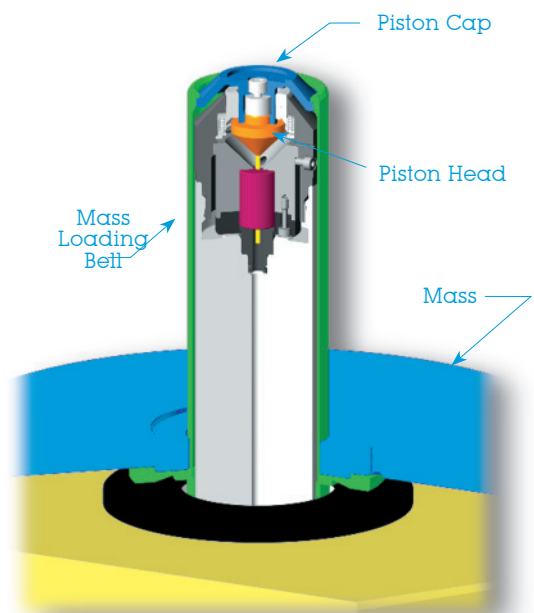
Installing Piston-Cylinder Module

- Improve piston-cylinder mounting design by allowing each mounting system to be optimized for a piston-cylinder size and range rather than accepting the compromises of a single, interchangeable mounting system.

## MASS LOADING CONCENTRICITY

Piston gauge performance is greatly affected by piston-cylinder verticality and mass loading concentricity. For optimum performance, the piston-cylinder axis must be aligned as well as possible with the acceleration due to gravity and the mass load must be concentric with the piston-cylinder axis.

Assuring piston-cylinder verticality and mass loading quality were key PG7000 design objectives. Piston-cylinder module alignment is established by the large diameter mating surface between the mounting post and the piston-cylinder module. The number of independent parts between the piston and mass load has been reduced to two (the piston cap and the mass loading bell). The piston head is effectively made part of the piston by machining it after installation concentric to the piston within  $\pm 20$  microns. PG7000 piston-cylinders have excellent mechanical characteristics but realizing their exceptional sensitivity and rotation times would not be possible without the special attention paid to alignment and mass loading quality.



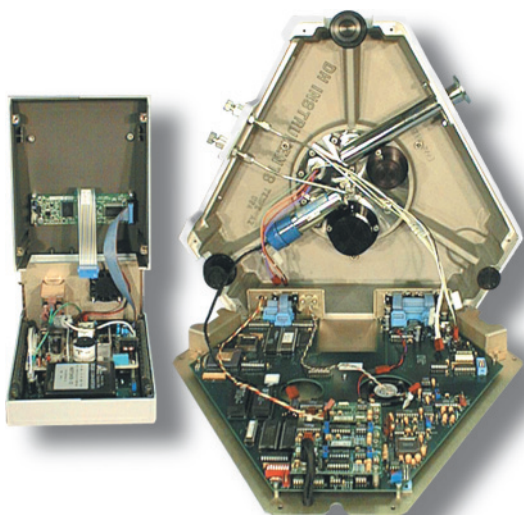
Mass Concentricity



## INTEGRATED ELECTRONICS, SOFTWARE AND REMOTE INTERFACING

PG7000 is a modern, digital instrument taking full advantage of today's sensor and data processing technologies supported by embedded software, an integrated local user interface and standard remote interfaces. Full feature operation is provided directly by the instrument itself without retrofits, add-on modules or external computers and software.

The electronics necessary for monitoring all ambient and instrument conditions and functions are integrated into the PG7000 platform. The display



PG Terminal and Platform Electronics

and keypad for the local operator are located on a compact terminal with the look and feel of other **DHI** products. The system power supplies are also contained in the terminal to remove their heat source from the PG platform.

Embedded software supports extensive on-board functions: displaying individual ambient condition variables and PG operating parameters... storing and recalling piston-cylinder and mass set metrological data... calculating fully compensated pressure to mass and mass to pressure values including all influences and head corrections... providing an objective, performance based go/no go indication of conditions for valid measurement.



PG Terminal

Local operator interaction with the PG7000, as with other modern test instruments, is through an integrated keypad and alphanumeric display not requiring an external computer or software. The keypad is function driven allowing rapid, intuitive operation. In addition, both RS232 and IEEE 488 interfaces with extensive, fully



PG Platform - Rear Connections

documented, ASCII string commands are included for remote communication.

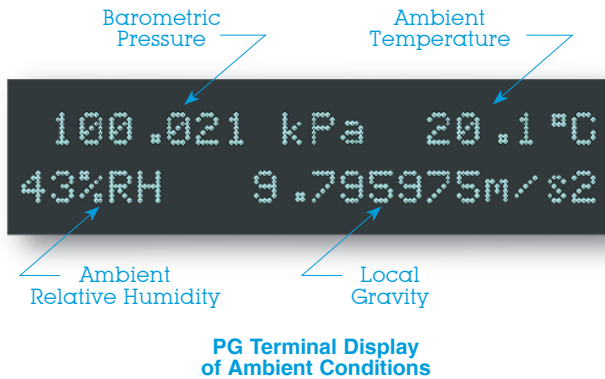
## ON-BOARD MEASUREMENT OF OPERATING CONDITIONS

PG7000 includes integrated on-board measurement of all the ambient and operating conditions needed to calculate pressure within tolerance. These include:

- Relative humidity - Capacitance sensor on PG platform rear panel.
- Barometric pressure - Internal piezoresistive sensor or by remote interfacing with any RS232 barometer.
- Ambient temperature - Platinum resistance thermometer mounted on PG platform rear panel.

- Piston-cylinder temperature - Platinum resistance thermometer embedded in piston-cylinder mounting post.
- Reference vacuum (PG7601 only) - Piranni gauge integrated directly under bell jar vacuum plate.

The individual measurements can be observed real time, both locally through the PG Terminal and remotely over the RS232 or IEEE 488 interface.

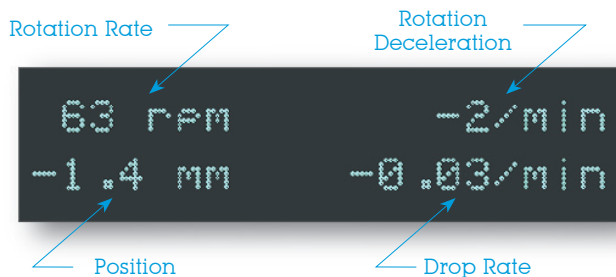


Provision for verification and recalibration of the on-board sensors is included and supported by PG7000's embedded software.

## MONITORING PISTON BEHAVIOR

Precise information on piston behavior is indispensable to achieving best performance with a high accuracy piston gauge. Piston position and fall rate are important to assure the piston is at the proper point in its stroke and falling at its natural rate. Piston rotation rate monitoring, though frequently ignored, is also very important to assure consistent operating conditions and detect possible piston-cylinder contamination.

PG7000 measures and provides real time indication of:



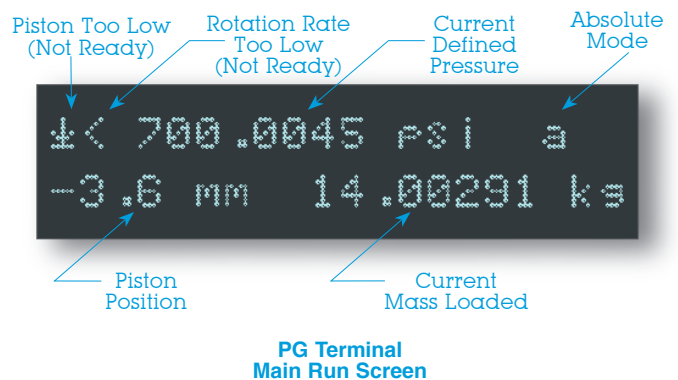
- Piston position
- Piston drop rate
- Piston rotation rate
- Piston rotation deceleration

Piston position is measured on the LVDT principle with a ring on the inside of the mass loading bell acting as the armature. Rotation rate is measured optically using a sensor in the mounting post which detects the movement of a notched ring on the inside of the mass loading bell. Both measurement systems are completely non-interfering. They have no influence on the free movement of the piston in any axis.

## READY/NOT READY INDICATION

PG7000 simplifies operation with a "ready/not ready" indication to provide the operator with a clear "go/no go" indication of when an in-tolerance measurement can be made.

The ready/not ready indication is based on testing for a variety of operating conditions including piston position, piston fall rate, piston rotation rate, piston rotation deceleration, piston temperature rate of change and vacuum reference (when applicable). A "ready" condition is indicated when all conditions fall within specific limits. If any condition is outside of limits, not ready is indicated with the responsible condition identified. The limits for the various "ready/not ready" criteria can be customized by the user if desired.

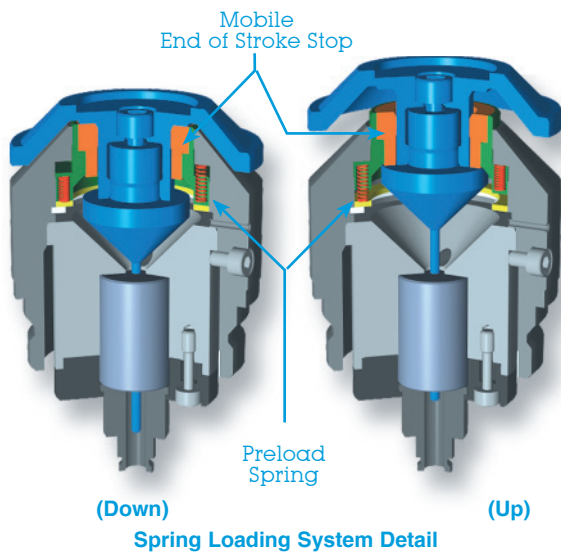


The "ready/not ready" feature assures that measurements are made under consistent conditions without requiring the operator to monitor multiple variables independently and/or make subjective judgements and decisions.

## PISTON NEAR-FLOAT DETECTION

Traditionally, one of the most tedious aspects of operating a piston gauge is adjusting pressure to float the piston. The procedure is delicate because the piston will lift, suddenly and without warning, only at the exact pressure corresponding to the mass loaded on the piston. Finding that point without overshooting requires slow and very cautious pressure control.

PG7000 makes it easier to float the piston (whether controlling pressure manually or automatically) with a piston preloading system that provides advance warning that the pressure is near the point where the piston will leave end of stroke. The preload is applied by spring loaded end of stroke stops. The spring force is equivalent to about



a 2 kg load on the piston. The preload causes the piston to begin moving away from end of stroke before the pressure under the piston is equivalent to the mass loaded on the piston. The early movement of the piston is detected by PG7000 and visual and audible warnings that the piston is about to leave end of stroke are provided. The preloading system only affects the piston when it is at end of stroke, it does not interfere with the free movement of the piston when it is floating.

The piston preload system provides advance warning of piston float making it easier to operate a PG7000. The spring loaded stops also

provide cushioning to dampen the impact when the piston reaches end of stroke to reduce wear and tear on the instrument.

## INTELLIGENT PISTON ROTATION

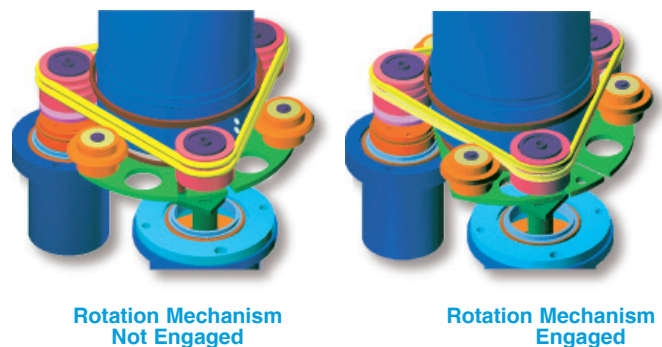
In high performance piston-cylinders, the piston must be rotated to operate properly.

The rotation sets up centering forces that keep the piston aligned in the cylinder assuring a uniform annular gap and the piston's freedom and mobility. For the most repeatable pressure measurements, it is important that the rotation rate be consistent. In addition, when measurements are made, no drive system can be engaged as it would contribute parasitic forces and unquantifiable errors.

PG7000 is the first commercially available piston gauge to provide monitoring of rotation rate and decay in rotation rate. These measurements, coupled with PG7000's internal logic, are used to assure that pressure readings are always made within rotation rate and decay in rotation rate limits. This relieves the operator of rotation rate monitoring responsibility and replaces subjective operator judgement with objective measurement.

In PG7000 platforms, the rotation stimulus may be provided either manually or by an optional motor drive. In most cases, manual rotation is adequate as PG7000 piston-cylinders require only occasional rotational acceleration and the rate of rotation monitoring system assures that measurements will be made within proper limits.

Motor driven rotation, when needed, is provided by a patented system that engages and disengages





intelligently, depending on current rate of rotation, to maintain the rotation rate within limits. Unlike conventional piston drive systems, drive contact never occurs randomly or without warning. The rotation system can engage with the piston in any position and does not significantly affect its position or the set pressure. A warning is provided when the rotation system is about to engage and while it is running. An override is available so that engagement will occur only on operator demand.

## STORAGE AND SHIPPING CONTAINERS

An important, but often overlooked, aspect of a high performance piston gauge package is its storage and shipping. Certain elements may only be used occasionally and recertification, particularly of the piston-cylinders and masses, is likely to require regular shipping off-site. In many cases, in-house shipping facilities are not aware of the need for special treatment of metrological items and are not properly equipped to package them adequately.

For PG7000 piston gauges the storing and shipping aspect has been carefully considered and addressed. The packaging provided for the piston gauge platform and mass set are heavy duty, weather proof, molded transit cases with custom inserts. These cases provide optimum protection and can be reused many times. PG7000 piston-cylinders modules are delivered in compact PVC bullet cases that are virtually indestructible.



Complete PG7000 System in Shipping Cases

They provide a convenient short term storage vehicle ensuring the module is always protected when not mounted in the piston gauge. The bullet cases also provide excellent shipping protection.

## ADVANCED PRESSURE GENERATION AND CONTROL COMPONENTS

In day to day operation, the operator's main interaction with a piston gauge based pressure calibration system is with the pressure generation and control components. These are used constantly, both for the large pressure changes between increments and to perform the fine adjustments needed to float and refloat the piston. Over the years, the ease of use and reliability of these components will weigh heavily in the system's value as a calibration tool.



MPC1 Manual Pressure Controller

The central role of pressure generation and control components in meeting PG7000's objectives was recognized at the start of the PG7000 development process and stayed at the forefront. All PG7000 pressure accessories were designed specifically for their application, searching out ways to increase the efficiency and ergonomics of piston gauge operation.

PG7000 introduced fully automated gas pressure control in a bench top piston gauge system which, coupled with PG7000's other intelligent features, leaves only loading and unloading masses in response to system prompts to the operator.

A manual gas pressure controller is also available. It is compact in size to facilitate system setup and features custom, soft grip valve knobs... not just a detail if you are the one using them day in and day out.





**OPG1**  
Hydraulic Pressure Generator / Controller

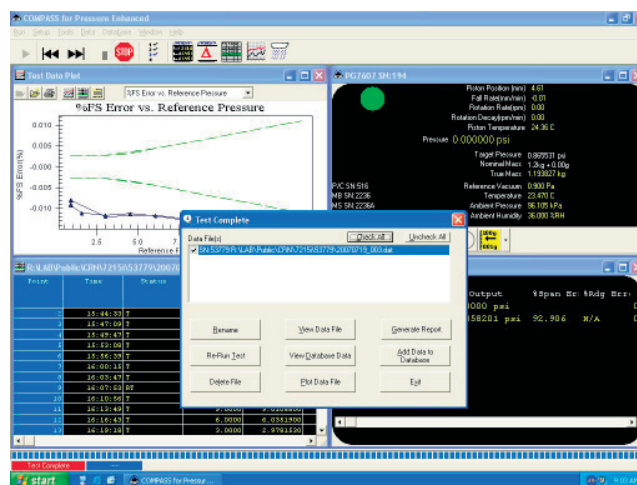
OPG1, the hydraulic pressure generator / controller for PG7302, breaks new ground in oil piston gauge operation. With a perfect balance between the benefits of automation and the practicality of direct operator control, it sets pressures effortlessly, precisely and very quickly, eliminating the pumping and screw press cranking for which oil piston gauges were once notorious.

## COMPASS® FOR PRESSURE CALIBRATION ASSISTANCE SOFTWARE

**COMPASS for Pressure** calibration assistance software takes PG7000 to the next step in automating calibrations.

Since PG7000 on-board electronics and software handle all the basic metrological and system monitoring aspects of PG7000 operation, COMPASS is not required to operate the system and make accurate measurements. COMPASS concentrates on optimizing the broader application of PG7000 in a calibration laboratory. COMPASS sets up device under test (DUT) records, defines and associates test procedures with DUTs, runs tests, acquires reference and test data, produces standard and custom calibration reports. All instrument, DUT and test data is collected

and stored in standard delimited files that can be easily downloaded to other applications.



**COMPASS® for Pressure Main Run Screen**

## A UNIFIED SOLUTION FROM VACUUM TO 500 MPA

From its inception, the PG7000 line of piston gauges was designed to cover the complete range of pressure from very low absolute and differential in gas, up to 500 MPa (75 000 psi) in oil. While several piston gauge platforms and specialized accessories, may be needed to cover different ranges and media, a consistent user interface and operational principles are maintained throughout the line. In most cases, complete gas and oil calibration capability can be achieved with just two PG platforms, four piston-cylinder modules and one mass set. This provides consistency from system to system which facilitates operation and training. Operators do not need to learn and operate several completely different systems to cover the full pressure range. Maintenance costs are reduced by minimizing the number of metrological elements to be supported.



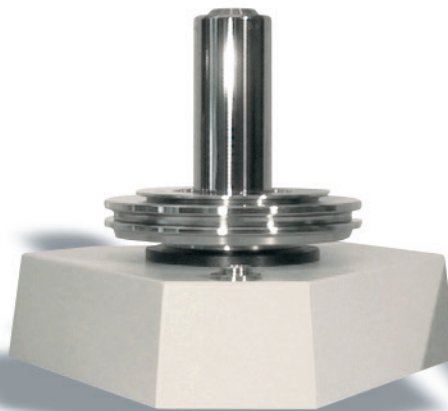
OPG1



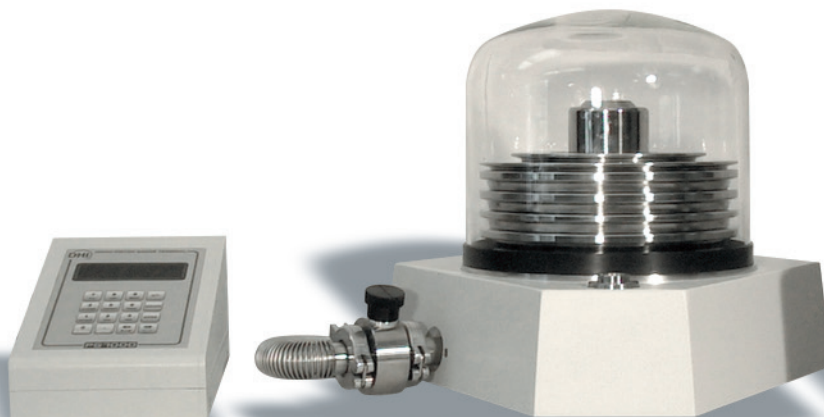
PG7302



MPC1



PG7102



PG7601



PPC3

# PG7302™ PLATFORM

OIL PRESSURES...  
from 100 kPa to 500 MPa (14.5 to 75 000 psi)

**PURPOSE:** PG7302 is recommended for covering gauge and absolute pressure with oil as the pressurized medium. Absolute mode is supported by automated measurement and addition of atmospheric pressure using PG7302's internal barometer or any external barometer supporting RS232 communications. To cover gas pressures under 11 MPa (1 600 psi), see PG7102 and PG7601. For information on covering gas pressures greater than 11 MPa (1 600 psi), please contact **DHI**.

**FEATURES:** Includes all PG7000 standard features (see pages 3 to 8) and the following:

- Special provisions for oil operation including a spent oil run off tray and a purging system to remove air under the piston during piston-cylinder module installation.
- Motorized piston rotation is optional (rotation rate monitoring and "ready/not ready" indication are always included) (see page 5).

## PUTTING TOGETHER A PG7302 SYSTEM

A typical PG7302 calibration systems consists of:

- **PG7302 Platform**  
See PG7302 Platform Ordering Information below.
- **Piston-Cylinder Modules**  
See pages 13 and 14 for information on PG7302 piston-cylinders and the ranges that they provide when combined with PG7302 mass set choices.
- **Mass Set**  
35, 40, 45, 55, 80 and 100 kg mass sets are available. See pages 15 and 16 for mass set information.

- **Pressure Generation/Control Component**

Choices available for PG7302 include:

- **OPG1-30000 Hydraulic Pressure Generator/Controller**  
Power assisted pressure generation and control to 200 MPa (30 000 psi) (see OPG1 brochure).
- **5:1 Intensifier Option**  
Extends OPG1-30000 pressure generation range to 500 MPa (75 000 psi).

Other optional accessories available:

- **RPM4-A0015 Reference Pressure Monitor**  
Interfaces directly with PG7302 to provide higher accuracy barometric pressure readings than the PG7302 on-board barometer (see RPM4 brochure). Recommended for operation in "absolute by addition of atmosphere" mode.
- **COMPASS® for Pressure**  
Applications software for IBM compatible PC that interfaces with PG7302 to support DUT records, running tests, acquiring data, and maintaining calibration records and generating reports, as well as providing enhanced operational monitoring displays.

## PG7302 PLATFORM ORDERING INFORMATION

<u>Designator</u>	<u>Part No.</u>	<u>Description</u>
PG7302	401297	Oil operated piston gauge
PG7302	401298	Oil operated piston gauge with motorized piston rotation
PG7302-CE	401297-CE	Oil operated piston gauge, CE compliant
PG7302-CE	401298-CE	Oil operated piston gauge, with motorized piston rotation, CE compliant

**PURPOSE:** PG7102 is recommended for covering gauge and absolute pressures above atmosphere with gas as the pressurized medium. Absolute mode is supported by automated measurement and addition of atmospheric pressure using PG7102's internal barometer or any external barometer supporting RS232 communications. PG7102 does not cover absolute or gauge pressures below atmospheric pressure. To cover absolute and gauge pressures near and under atmosphere and/or for best accuracy on absolute pressures under about 1 500 kPa (200 psi), use PG7601 (see page 12). For information on covering gas pressures greater than 11 MPa (1 600 psi), please contact **DHI**.

**FEATURES:** Includes all PG7000 standard features (see pages 3 to 8) and the following:

- Lower cost, simplified gas operated platform does not include vacuum reference capability.
- Motorized piston rotation is optional (rotation rate monitoring and ready/not ready indication are always included) (see page 5).

### PUTTING TOGETHER A PG7102 SYSTEM

A typical PG7102 calibration systems consists of:

- **PG7102 Platform**  
See PG7102 Platform Ordering Information below.
- **Piston-Cylinder Modules**  
See pages 13 and 14 for information on PG7102 piston-cylinders and the ranges that they provide when combined with PG7102 mass set choices.
- **Mass Set**  
35, 40, 45 and 55 kg mass sets are available. See pages 15 and 16 for mass set information.

- **Pressure Generation/Control Component**

Choices available for PG7102 include:

- **MPC1-1000**  
Manual pressure control up to 7 MPa (1 000 psi) (see MPC1 brochure).
- **MPC1-3000**  
Manual pressure control up to 20 MPa (3 000 psi) (see MPC1 brochure).
- **PPC3-7Mu**  
Automated pressure control up to 7 MPa (1 000 psi) (see PPC3 brochure).
- **Interconnections Kit**  
To connect the PG7102 to the pressure generation/control component and provide a quick-connector test connection. P/N 400985, PK-7000-PPC/MPC, Interconnections kit.

Other optional accessories available:

- **RPM4-A0015 Reference Pressure Monitor**  
Interfaces directly with PG7102 to provide higher accuracy barometric pressure readings than the PG7102 on-board barometer (see RPM4 brochure). Recommended for operation in "absolute by addition of atmosphere" mode.
- **COMPASS® for Pressure**  
Applications software for IBM compatible PC that interfaces with PG7102 to support DUT records, running tests, acquiring data, maintaining calibration records and generating reports as well as providing enhanced operational monitoring displays.

### PG7102 PLATFORM ORDERING INFORMATION

<u>Designator</u>	<u>Part No.</u>	<u>Description</u>
PG7102	401140	Gas operated piston gauge
PG7102	401141	Gas operated piston gauge, with motorized piston rotation
PG7102-CE	401140-CE	Gas operated piston gauge, CE compliant
PG7102-CE	401141-CE	Gas operated piston gauge with motorized piston rotation, CE compliant



# PG7601™ PLATFORM

## GAS PRESSURES WITH VACUUM REFERENCE... from 5 kPa to 7 MPa (0.7 to 1 000 psi)

**PURPOSE:** PG7601 is recommended for covering absolute and gauge pressures with gas including pressures near and under atmospheric pressure. PG7601 measurements can be referenced to vacuum by evacuating the bell jar that covers the mass load. If absolute and gauge pressures near and under atmosphere are not required and/or pressure greater than 7 MPa (1 000 psi) is required, PG7102, which does not include vacuum reference capability, should be considered.

**FEATURES:** Includes all PG7000 standard features (see pages 3 to 8) and the following:

- Supports establishing and measuring a vacuum reference for defining absolute pressures relative to an evacuated bell jar. Includes bell jar and integrated vacuum gauge.
- Supports "differential mode" operation to cover positive and negative differential pressures near zero and at different static pressures (see Technical Note 9940TN02).

### PUTTING TOGETHER A PG7601 SYSTEM

A typical PG7601 calibration systems consists of:

- **PG7601 Platform**  
See PG7601 Platform Ordering Information below.
- **Piston-Cylinder Modules**  
See pages 13 and 14 for information on PG7601 piston-cylinders and the ranges they provide when combined with the PG7601 mass set.
- **35 kg Mass Set**  
See pages 15 and 16 for mass set information.
- **Pressure Generation/Control Component**  
Choices available for PG7601 include:
  - **MPC1-1000**  
Manual pressure control up to 7 MPa (1 000 psi) (see MPC1 brochure).
  - **PPC3-7Mu**  
Automated pressure control up to 7 MPa (1 000 psi) (see PPC3 brochure).

- **Interconnections Kit**

Choices available for PG7601 include:

- To connect PG7601 to the pressure generation/control component and provide a quick-connector test connection. P/N 400985, PK-7000-PPC/MPC, interconnections kit.
- To connect PG7601 to the pressure generation/control component and provide test connections and valving for differential mode operation, P/N 401581, PK-7600-PPC/MPC-DIF (see Technical Note 9940TN02).

- **Vacuum Pumps and Accessories**

- Vacuum pump and accessories to establish vacuum under the PG7601 bell jar, P/N 401209, VA-7601-REF (110V) or P/N 401453 (220 V).
- Vacuum pump and accessories to set pressure under atmosphere using PPC3 or MPC1, VA-PPC/MPC-REF, P/N 400922 (110 V) or P/N 401160 (220 V).

Other optional accessories available:

- **RPM4-A0015 Reference Pressure Monitor**  
Interfaces directly with PG7601 to provide higher accuracy barometric pressure readings than the PG7601 on-board barometer (see RPM4 brochure). Required for "differential mode" operation.
- **COMPASS® for Pressure**  
Applications software for IBM compatible PC that interfaces with PG7601 to support DUT records, running tests, acquiring data, maintaining and generating calibration records as well as providing enhanced operational monitoring displays.

### PG7601 PLATFORM ORDERING INFORMATION

<u>Designator</u>	<u>Part No.</u>	<u>Description</u>
PG7601	400480	Gas operated piston gauge, with motorized piston rotation
PG7601-CE	400480-CE	Gas operated piston gauge, with motorized piston rotation, CE compliant

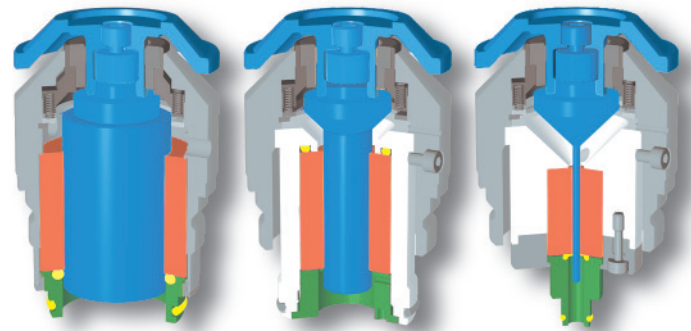
The piston-cylinder defines effective area and is the piston gauge's principal metrological element. The piston-cylinder's intrinsic characteristics and how it is mounted and exploited are the keys to piston gauge performance.

PG7000 piston-cylinders are manufactured by **DHI** using proprietary production techniques developed specifically for the PG7000 series. These result in pistons and cylinders whose typical shape is within less than 0.2 micron from ideal geometry. Gas operated piston-cylinders use large diameters and very small annular gaps to minimize gas species and operating mode effects and to maximize piston float times. For example, the typical annular gap of a 35 mm gas operated piston-cylinder is less than 1 micron. Oil operated piston-cylinders use small diameters to reduce the quantity of mass needed to cover the typical high pressure range.



All Type 7000 pistons and cylinders are made of tungsten carbide except the standard 35 mm gas operated piston which is made of high purity ceramic to reduce its mass and thus its minimum starting pressure. Each PG7000 piston-cylinder is a complete, integrated metrological assembly that includes the critical piston-cylinder mounting components. This approach improves metrological performance as well as offering many practical advantages (see page 3).

All Type 7000 piston-cylinders use free deformation mounting systems in which the cylinder is allowed to deform under the



Simple  
Free Deformation,  
Gas

Negative  
Free Deformation,  
Gas

Simple  
Free Deformation,  
Oil

influence of applied pressure without O-rings or seals along the cylinder length. For the higher pressure gas assemblies, a new mounting system designated negative free deformation has been developed. Negative free deformation applies the measured pressure uniformly along the full length of the cylinder. This reduces deformation under pressure so that piston drop rates remain low, even at high operating pressures while avoiding the unpredictable strain points of conventional reentrant designs.

## PISTON-CYLINDER MODULE ORDERING INFORMATION

Designator	Part No.	Description
PC-7100/7600-10-L	402432	Gas P-C module
PC-7100/7600-10, TC	401562	Gas P-C module
PC-7100/7600-50	401563	Gas P-C module
PC-7100/7600-200	401564	Gas P-C module
PC-7300-100	401552	Oil P-C module
PC-7300-200	401553	Oil P-C module
PC-7300-500	401554	Oil P-C module
PC-7300-2	401556	Oil P-C module
PC-7300-5	401557	Oil P-C module

Each PG7000 piston-cylinder is delivered complete with:

- **PVC "Bullet" Case**
- **Calibration Report**

Reporting complete technical characteristics and effective area traceable to the United States National Institute of Standards and Technology (NIST).

**Note:** Consult **DHI** about converting existing Type 5000 piston-cylinders for use in a Type 7000 piston gauge.

## GAS OPERATED PISTON-CYLINDERS FOR PG7102 AND PG7601

### Ranges

DESIGNATOR	PRESSURE TO MASS [kg]	MINIMUM PRESSURE						MAXIMUM PRESSURE (depending on mass set)							
		PG7102/7601 (piston only)		PG7102 (piston & bell)		PG7601 (piston & bell)		35 kg		40 kg		45 kg		55 kg	
		[kPa]	[psi]	[kPa]	[psi]	[kPa]	[psi]	[kPa]	[psi]	[kPa]	[psi]	[kPa]	[psi]	[kPa]	[psi]
PC-7100/7600-10-L	10 kPa	4	0.6	12	1.7	7	1	350	50	400	60	450	65	550	80
PC-7100/7600-10, TC	10 kPa	5	0.7	13	2.0	8	1.2	350	50	400	60	450	65	550	80
PC-7100/7600-20	20 kPa	4	0.6	20	3.0	10	1.4	700	100	800	120	900	130	1100	160
PC-7100/7600-50	50 kPa	10	1.5	50	7.5	25	3.7	1 750	250	2 000	300	2 250	325	2 750	400
PC-7100/7600-100	100 kPa	20	2.9	100	14.5	50	7.25	3 500	500	4 000	600	4 500	650	5 550	800
PC-7100/7600-200	200 kPa	40	5.8	200	29.0	100	14.5	7 000	1 000	8 000	1 200	9 000	1 300	11 000	1 600

Optimal performance starts with the piston and mass bell loaded. PG7601 only accepts a 35 kg mass set (MS-7001-35).

### Technical Characteristics

DESIGNATOR	NOMINAL DIAMETER [mm]	NOMINAL AREA [mm <sup>2</sup> ]	PISTON ASSEMBLY MASS [g]	PISTON MATERIAL	CYLINDER MATERIAL	MOUNTING SYSTEM
PC-7100/7600-10-L	35	980	400	Tungsten Carbide	Tungsten Carbide	Simple Free Deformation
PC-7100/7600-10, TC	35	980	500	Tungsten Carbide	Tungsten Carbide	Simple Free Deformation
PC-7100/7600-20	25	500	200	Tungsten Carbide	Tungsten Carbide	Simple Free Deformation
PC-7100/7600-50	16	196	200	Tungsten Carbide	Tungsten Carbide	Negative Free Deformation
PC-7100/7600-100	11	100	200	Tungsten Carbide	Tungsten Carbide	Negative Free Deformation
PC-7100/7600-200	8	50	200	Tungsten Carbide	Tungsten Carbide	Negative Free Deformation

## OIL OPERATED PISTON-CYLINDERS FOR PG7302

### Ranges

DESIGNATOR	PRESSURE TO MASS [kg]	MINIMUM PRESSURE				MAXIMUM PRESSURE (depending on mass set)											
		(piston only)		(piston & bell)		35 kg		40 kg		45 kg		55 kg		80 kg		100 kg	
		[kPa]	[psi]	[kPa]	[psi]	[MPa]	[psi]	[MPa]	[psi]	[MPa]	[psi]	[MPa]	[psi]	[MPa]	[psi]	[MPa]	[psi]
PC-7300-100	100 kPa	20	3	100	15	3.5	500	4	600	4.5	650	5.0	725	8.0	1 150	10.0	1 450
PC-7300-200	200 kPa	40	5	200	29	7.0	1 000	8	1 200	9.0	1 300	11.0	1 600	16.0	2 300	20.0	2 900
PC-7300-500	500 kPa	100	15	500	73	17.5	2 500	20	3 000	22.5	3 250	27.5	4 000	40.0	5 800	50.0	7 250
PC-7300-1	1 MPa	200	30	1 000	145	35.0	5 000	40	6 000	45.0	6 500	55.0	8 000	80.0	11 500	100.0	14 500
PC-7300-2	2 MPa	400	60	2 000	290	70.0	10 000	80	12 000	90.0	13 000	110.0	16 000	160.0	23 000	200.0	29 000
PC-7300-5	5 MPa	1 000	145	5 000	725	175.0	25 000	200	30 000	225.0	32 500	275.0	40 000	400.0	58 000	500.0	72 500

Optimal performance starts with the piston and mass bell loaded.

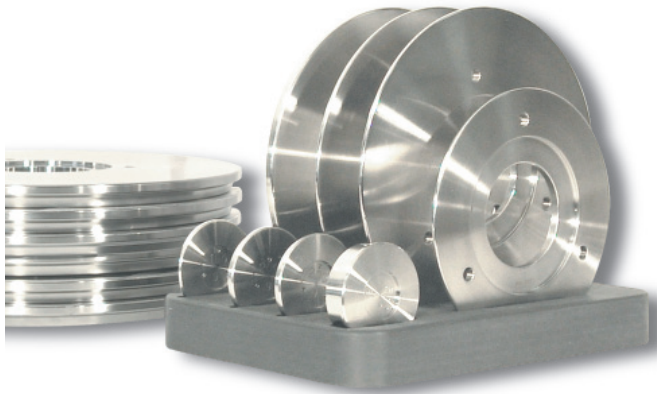
### Technical Characteristics

DESIGNATOR	NOMINAL DIAMETER [mm]	NOMINAL AREA [mm <sup>2</sup> ]	PISTON ASSEMBLY MASS [g]	PISTON MATERIAL	CYLINDER MATERIAL	MOUNTING SYSTEM
PC-7300-100	11.2	98.5	200	Tungsten Carbide	Tungsten Carbide	Simple Free Deformation
PC-7300-200	7.9	49.0	200	Tungsten Carbide	Tungsten Carbide	Simple Free Deformation
PC-7300-500	5.0	19.6	200	Tungsten Carbide	Tungsten Carbide	Simple Free Deformation
PC-7300-1	3.5	9.8	200	Tungsten Carbide	Tungsten Carbide	Simple Free Deformation
PC-7300-2	2.5	4.9	200	Tungsten Carbide	Tungsten Carbide	Simple Free Deformation
PC-7300-5	1.6	1.9	200	Tungsten Carbide	Tungsten Carbide	Simple Free Deformation

Masses are loaded on the piston and accelerated by gravity to apply a known force on the piston against which the defined pressure is balanced.

A complete PG7000 mass set includes main masses of 10 or 5 kg each, fractionary masses in 5-2-2-1 progression from 0.5 to 0.1 kg and a trim mass set with masses from 50 to 0.01 g. The mass set composition is such that any desired mass value within the mass set range can be loaded within 0.01 g. Different size mass sets and piston-cylinder choices provide flexibility in putting together a PG7000 system whose ranges best fit your needs.

All main masses are machined from solid, non-magnetic stainless steel and adjusted to their nominal values in the mass without cavities or trimming hardware which can reduce mass stability over time. For specifications on individual masses see page 18.



Mass Set on Mass Tray

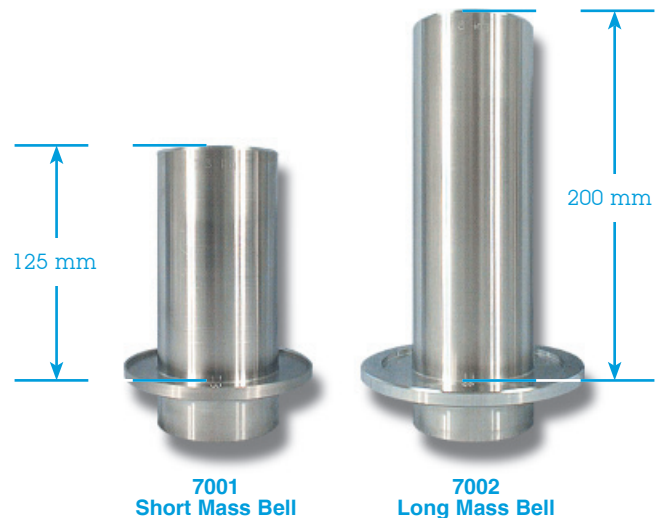
Since loading and unloading masses is one of the most common operator interactions with a PG7000 system, the individual masses and the mass set have been designed to maximize handling convenience. Ample angled lifting surfaces are provided on the edge of each mass and special mass trays are included to assist in orderly mass loading and unloading.

Standard PG7000 pistons are adjusted to a mass of 0.2 kg. The first mass loaded on the piston is the mass loading bell onto which all the other masses are loaded. The mass loading bell is delivered with the PG platform. There are two different mass



Mass Transit Cases

loading bells. The 7001 bell is a short bell that fits under the PG7601's bell jar. The 7002 bell is a longer bell used on all the other PG7000 models. The 7001 bell has a mass of 0.3 kg; the 7002 bell has a mass of 0.8 kg. Both bells are made of titanium to minimize their mass.





## PG7000 MASS SET DEFINITIONS

DESIGNATOR	PART NO.	NOMINAL TOTAL MASS [kg]	MASS SET COMPOSITION								TRIM SET 50 to 0.1 g	MAKE UP MASS <sup>(1)</sup> [kg]	PISTON <sup>(1)</sup> [kg]	BELL <sup>(1)</sup> [kg]
			10 kg	5 kg	2 kg	1 kg	0.5 kg	0.2 kg	0.1 kg					
MS-7001-35	401425	35	--	5	2	1	1	2	1	1	1 (4.5)	0.2 <sup>(2)</sup>	0.3	
MS-7002-35	401426	35	--	5	2	1	1	2	1	1	1 (4)	0.2	0.8	
MS-7002-40	401522	40	--	6	2	1	1	2	1	1	1 (4)	0.2	0.8	
MS-7002-45	401496	45	--	7	2	1	1	2	1	1	1 (4)	0.2	0.8	
MS-7002-55	401427	55	--	9	2	1	1	2	1	1	1 (4)	0.2	0.8	
MS-7002-80	401518	80	6	1	2	1	1	2	1	1	1 (9)	0.2	0.8	
MS-7002-100	401519	100	8	1	2	1	1	2	1	1	1 (9)	0.2	0.8	

**Note:** The piston and the mass loading bell are not included in the mass set. Piston-cylinders are ordered separately and the mass loading bell is delivered with the PG7000 platform.

<sup>(1)</sup> The make up mass is the first main mass loaded on the piston and bell to reach an even increment of 5 or 10 kg.

<sup>(2)</sup> PC-7100/7600-10, TC with a tungsten carbide piston has a piston mass of 0.5 kg.

## MASS SET COMPATIBILITY

DESIGNATOR	NOMINAL TOTAL MASS [kg]	PG7102	PG7302	PG7601
MS-7001-35	35			●
MS-7002-35	35	●	●	
MS-7002-40	40	●	●	
MS-7002-45	45	●	●	
MS-7002-55	55	●	●	
MS-7002-80	80		●	
MS-7002-100	100		●	

## MASS SET ORDERING INFORMATION

Designator	Part No.	Description
MS-7001-35	401425	35 kg mass set, w/4.5kg make up
MS-7002-35	401426	35 kg mass set, w/4 kg make up
MS-7002-40	401522	40 kg mass set, w/4 kg make up
MS-7002-45	401496	45 kg mass set, w/4 kg make up
MS-7002-55	401427	55 kg mass set, w/4 kg make up
MS-7002-80	401518	80 kg mass set, w/9 kg make up
MS-7002-100	401519	100 kg mass set, w/9 kg make up

Each PG7000 mass set is delivered complete with:

- Shipping and Storage Cases (molded, reusable)
- Mass Trays
- Dust Cover
- Calibration Report

Reporting complete technical characteristics and true mass values traceable to the United States National Institute of Standards and Technology (NIST).



## GENERAL

**Power Requirements:** 85 to 264 VAC, 47 to 440 Hz,  
22 VA max consumption

**Operating Temperature Range:** 15 to 35 °C

**Weight:** Instrument platform with no mass loaded

PG7102 13 kg (28 lb)

PG7302 13 kg (28 lb)

PG7601 17 kg (37 lb)

PG Terminal 1.4 kg (3 lb)

### Dimensions:

**Instrument Platform** 36 cm H x 40 cm W x 35 cm D  
(14.5 in x 15.8 in x 13.8 in)  
(Height: Top of mounting post with piston-cylinder module installed for PG7102/PG7302; top of bell jar for PG7601)

**PG Terminal** 12 cm H x 15 cm W x 20 cm D  
(4.7 in x 5.9 in x 7.9 in)

### Microprocessors:

**Instrument Platform** Motorola 68302

**PG Terminal** Hitachi 64180

### Communications Ports:

**RS-232** COM1: Host computer  
COM2: External barometer  
COM3: Automated pressure controller

**IEEE-488.2** Host computer

### Maximum

### Pressure Ranges:

Actual range depends on piston-cylinder and mass set selection.

**PG7102** Gauge: 10 kPa to 11 MPa (1.5 to 1 600 psi)  
Absolute: 110 kPa to 11 MPa (16 to 1 600 psi)

**PG7302** Gauge: 100 kPa to 500 MPa (15 to 75 000 psi)  
Absolute: 200 kPa to 500 MPa (30 to 75 000 psi)

**PG7601** Gauge: 5 kPa to 7 MPa (0.7 to 1 000 psi)  
Absolute: 5 kPa to 7 MPa (0.7 to 1 000 psi)  
Differential: -90 to 350 kPa (16 to 1 600 psi)  
at line pressure of 15 to 200 kPa absolute  
(2.2 to 30 psi)

### Operating Media:

**PG7102** Gas: air, helium, nitrogen

**PG7302** Oil: Di2-Ethyl Hexyl Sebacate (oil)

**PG7601** Gas: air, helium, nitrogen

### Maximum Mass Load:

**PG7102** 55 kg

**PG7302** 100 kg

**PG7601** 35 kg

### Pressure Connections:

**Test Port** PG7102: DH200

PG7302: DH500

PG7601: DH200

Note: DH200 and DH500 are gland and collar type fittings for 1/4 in (6 mm) coned and left hand threaded tube. DH200 is equivalent to AE SF250C, HIP LF4, etc. DH500 is equivalent to AE F250C, HIP HF4, etc.

**PG7601 Only** Bell Jar Vent Port: DH200

Vacuum Pump Down Port: KF25

**CE Conformance:** Available, must be specified

## EMBEDDED FEATURES

- Local control with 2 x 20 electroluminescent and 4 x 4 function driven keypad.

- Real time (1 second update rate) display and measurement of ambient (pressure, temperature, humidity) and instrument (piston-cylinder temperature, piston position, piston drop rate, piston rotation rate, piston rotation decay rate) conditions.
- Real time (1 second update rate) mass to pressure and pressure to mass calculations taking into consideration all environmental and operational variables.
- Gas and liquid head corrections.
- Adjustable mass loading resolution (0.1 kg to 0.01 g).
- Audible prompts of instrument status with override capability.
- Interfacing and automatic exploitation of any external barometer (RS232).
- Storage and one step activation of metrological data on up to 18 piston-cylinder modules and 3 mass sets.
- Continuous pressure ready/not ready indication based on measured conditions for valid measurement.
- Intelligent piston drive system based on measured rotation rate with operator alert and manual override (optional on PG7102, PG7302).
- Built-in drivers for automated pressure control components with override capability.
- Full RS232 and IEEE-488.2 communications with multi-level commands to set and read all instrument functions.

## AMBIENT AND INSTRUMENT CONDITION MEASUREMENTS

Temperature:	Ambient [°C]	Piston-Cylinder Module [°C]
Range	0 to 40	0 to 40
Resolution	0.1	0.01
Accuracy	± 1	± 0.1

### Barometric Pressure with Internal Sensor:

Range	70 to 110 kPa
Resolution	10 Pa
Accuracy	± 140 Pa

Barometric pressure can also be read automatically from any RS232 device such as **DHI** RPM4.

### Relative Humidity:

Range	5 to 95 %RH
Resolution	1 %RH
Accuracy	± 10 %RH

### Piston Position:

Range	± 4.5 mm
Resolution	0.1 mm
Accuracy	± 0.2

### Piston Rotation:

Range	(Rate and Deceleration)
Resolution	2 to 150 rpm
Accuracy	1 rpm

### Vacuum:

Range	(PG7601 only)
Resolution	0 to 20 Pa
Accuracy	0.01 Pa
	± 0.1 Pa or 10% of reading, whichever is greater

## MASSES (see pages 15 and 16)

All masses are delivered in molded, reusable transit cases with custom inserts.

### Masses > 50 g:

Material	304L non-magnetic stainless steel
Finish	Eletropolished

Adjustment Tolerance ± 20 ppm of nominal value

Accuracy of Measured Values ± 5 ppm or 1 mg, whichever is greater

Traceability of Measured Values National Institute of Standards and Technology (NIST)

**Masses ≤ 50 g:** Conform to NIST S1

## PISTON-CYLINDER MODULES (see pages 13 and 14)

All piston-cylinders are integrated modules including mounting hardware delivered in individual shipping and storage bullet cases.

<b>Cylinder Material:</b>	Tungsten carbide
<b>Piston Material:</b>	Tungsten carbide
<b>Mounting System:</b>	
PC-7200-x	Negative free deformation
PC-7100/7600-50, -100, -200	Negative free deformation
All Others	Simple free deformation

## PRESSURE MEASUREMENT

### PG7102/7601:

#### PC-7100/7600-10-L and -10, TC

Sensitivity <sup>1</sup>	0.02 Pa + 0.5 ppm
Reproducibility <sup>2</sup>	± 2 ppm
Uncertainty <sup>3</sup>	± (0.2 Pa + 12 ppm)
Typical Drop Rate -10, TC <sup>4</sup>	0.2 mm/min @350 kPa
Typical Drop Rate 10-L <sup>4</sup>	0.15 mm/min @350 kPa

#### PC-7100/7600-20

Sensitivity <sup>1</sup>	0.04 Pa + 0.5 ppm
Reproduceability <sup>2</sup>	± 2 ppm
Uncertainty <sup>3</sup>	± (0.2 Pa + 14 ppm)
Typical Drop Rate <sup>4</sup>	0.3 mm/min @700 kPa

#### PC-7100/7600-50

Sensitivity <sup>1</sup>	0.1 Pa + 0.5 ppm
Reproduceability <sup>2</sup>	± 2 ppm
Uncertainty <sup>3</sup>	± (0.5 Pa + 14 ppm)
Typical Drop Rate <sup>4</sup>	0.5 mm/min @1750 kPa

#### PC-7100/7600-100

Sensitivity <sup>1</sup>	0.2 Pa + 0.5 ppm
Reproduceability <sup>2</sup>	± 3 ppm
Uncertainty <sup>3</sup>	± (1 Pa + 20 ppm)
Typical Drop Rate <sup>4</sup>	0.7 mm/min @3500 kPa

#### PC-7100/7600-200

Sensitivity <sup>1</sup>	0.4 Pa + 0.5 ppm
Reproduceability <sup>2</sup>	± 3 ppm
Uncertainty <sup>3</sup>	± (2 Pa + 20 ppm)
Typical Drop Rate <sup>4</sup>	1.0 mm/min @7000 kPa

### PG7202:<sup>5</sup>

#### PC-7202-100

Sensitivity <sup>1</sup>	2 Pa + 1 ppm
Reproduceability <sup>2</sup>	± 2 ppm
Uncertainty <sup>3</sup>	± (2 Pa + 20 ppm)
Typical Drop Rate <sup>4</sup>	0.10 mm/min @5 MPa

#### PC-7202-200

Sensitivity <sup>1</sup>	4 Pa + 1 ppm
Reproduceability <sup>2</sup>	± 3 ppm
Uncertainty <sup>3</sup>	± (3 Pa + 20 ppm)
Typical Drop Rate <sup>4</sup>	0.15 mm/min @10 MPa

#### PC-7202-500

Sensitivity <sup>1</sup>	10 Pa + 1 ppm
Reproduceability <sup>2</sup>	± 3 ppm
Uncertainty <sup>3</sup>	± [7 Pa + (18 ppm +0.15 ppm/MPa)]
Typical Drop Rate <sup>4</sup>	0.20 mm/min @25 MPa

#### PC-7202-1

Sensitivity <sup>1</sup>	20 Pa + 1 ppm
Reproduceability <sup>2</sup>	± 3 ppm
Uncertainty <sup>3</sup>	± [15 Pa + (20 ppm +0.15 ppm/MPa)]
Typical Drop Rate <sup>4</sup>	0.25 mm/min @50 MPa

#### PC-7202-2

Sensitivity <sup>1</sup>	40 Pa + 1 ppm
Reproduceability <sup>2</sup>	± 4 ppm
Uncertainty <sup>3</sup>	± [30 Pa + (30 ppm +0.15 ppm/MPa)]
Typical Drop Rate <sup>4</sup>	0.50 mm/min @100 MPa

### PG7302:

#### PC-7300-100

Sensitivity <sup>1</sup>	2 Pa + 1 ppm
Reproduceability <sup>2</sup>	± 2 ppm
Uncertainty <sup>3</sup>	± (16 Pa + 18 ppm)
Typical Drop Rate <sup>4</sup>	0.02 mm/min @5 MPa

#### PC-7300-200

Sensitivity <sup>1</sup>	4 Pa + 1 ppm
Reproduceability <sup>2</sup>	± 3 ppm
Uncertainty <sup>3</sup>	± (16 Pa + 20 ppm)
Typical Drop Rate <sup>4</sup>	0.04 mm/min @10 MPa

#### PC-7300-500

Sensitivity <sup>1</sup>	10 Pa + 1 ppm
Reproduceability <sup>2</sup>	± 3 ppm
Uncertainty <sup>3</sup>	± (20 Pa + 20 ppm)
Typical Drop Rate <sup>4</sup>	0.10 mm/min @25 MPa

#### PC-7300-1

Sensitivity <sup>1</sup>	20 Pa + 1 ppm
Reproduceability <sup>2</sup>	± 3 ppm
Uncertainty <sup>3</sup>	± (25 Pa + 25 ppm)
Typical Drop Rate <sup>4</sup>	0.2 mm/min @50 MPa

#### PC-7300-2

Sensitivity <sup>1</sup>	40 Pa + 1 ppm
Reproduceability <sup>2</sup>	± 4 ppm
Uncertainty <sup>3</sup>	± [40 Pa + (25 ppm +0.04 ppm/MPa)]
Typical Drop Rate <sup>4</sup>	0.40 mm/min @100 MPa

#### PC-7300-5

Sensitivity <sup>1</sup>	100 Pa + 1 ppm
Reproduceability <sup>2</sup>	± 6 ppm
Uncertainty <sup>3</sup>	± [100 Pa + (35 ppm + 0.04 ppm/MPa)]
Typical Drop Rate <sup>4</sup>	1.0 mm/min @250 MPa

## STANDARD ACCESSORIES

### PG7000 Platforms

- Mass loading bell
- Reusable molded transit case with custom inserts
- Power cord
- Instrument dust cover
- Technical data report
- Adaptor for test connection (depends on model)
- Dust cover
- Wear subjected parts kit
- Bell jar (PG7601 only)
- KF 25 plug, O-ring assembly and clamp for reference vacuum connection (PG7601 only)
- Calibration report

### PG7000 Mass Sets

- Reusable molded transit case with custom inserts
- Mass presentation tray
- Dust cover
- Calibration report

### PG7000 Piston-Cylinders

- Bullet case
- Calibration report

<sup>1</sup> Sensitivity: The smallest variation in input detectable in output. Sensitivity is given as a full uncertainty (2a) at k=2. k=1 value is obtained by dividing each part by the square root of 12.

<sup>2</sup> Reproducibility: Combined long term stability of piston-cylinder effective area and masses.

<sup>3</sup> Typical Pressure Measurement Uncertainty: All relevant sources of uncertainty under typical operating conditions are identified, quantified and combined following the "Guide to the Expression of Uncertainty in Measurement (GUM)". DHI Technical Note 7920TN01 (latest revision) documents the detailed uncertainty analysis for each platform, piston-cylinder and operating mode, and can be used to derive uncertainty in pressure in a user's specific conditions. Uncertainties are for manual mass loading. The use of AMH improves uncertainty for some ranges.

<sup>4</sup> Typical Drop Rate: Typical drop rate at the pressure given.

<sup>5</sup> PG7202 is a PG7000 platform designed for high pressure gas measurement to 100 MPa. See PG7202 brochure, 2010.2.A.5.



## SOME USERS... WORLDWIDE...

### AEROSPACE

CalSpan  
DGA/CEV  
General Electric

IHI  
Korean Air  
Lockheed Martin

NASA

### AUTOMOTIVE / HEAVY EQUIPMENT

Chrysler Corporation  
Cummins Engine  
Delco Electronics

General Motors  
Hyundai Motor Co.  
Peugeot

Samsung Motors

### ENERGY

CFE LAPEM  
China Electric Power  
Commonwealth Edison

Detroit Edison  
Korea Gas  
Rochester Gas & Electric

Severomoravska Plynarenska  
Southern California Edison  
Schlumberger

### INSTRUMENT MANUFACTURER

Beamex  
Daesung Electric  
Honeywell

Paroscientific  
Pressure Systems  
Rosemount

Sanko Controls  
Yamatake  
Yokogawa

### NATIONAL METROLOGY LABORATORIES

CENAM - Mexico  
CMA - Finland  
CMI - Czech Republic  
KRISS - Korea  
LNE - France

MSL - New Zealand  
NIM - China  
NIST - USA  
NMI - Netherlands  
NML - South Africa

NRC - Canada  
NRLM - Japan  
NSL - New Zealand  
PTB - Germany  
UME - Turkey

### OTHER

Japan Quality Association  
LG International  
Motorola

Transcat  
University of Idaho  
University of Florida

US Air Force  
US Navy

Represented  
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