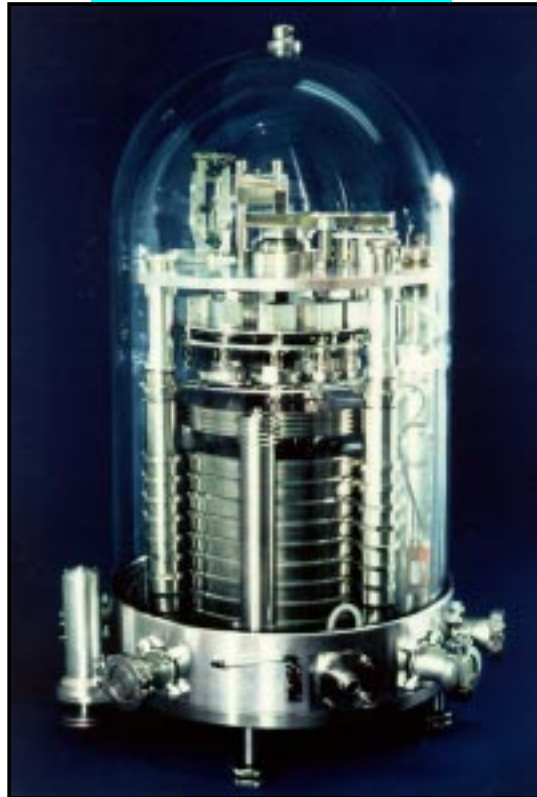


METROLOGY RANGE



APX50

Automatic Absolute Pressure Balance

DH·BUDENBERG's latest development, combined with the BNM-LNE's metrological expertise, results in the leading APX50 absolute pressure balance.

The APX50 is very well suited for the calibration of absolute dead-weight testers, mano-barometers and quartz transducers.

This standard is now the new National absolute pressure Reference of the French calibration chain.

- HIGHEST LEVEL ACHIEVABLE UNCERTAINTY OF $5 \cdot 10^{-6}$ WITH $K=2$
- PRIMARY STANDARD
- ABSOLUTE/GAUGE PRESSURE MEASUREMENT
- AUTOMATIC MASS LOADING
- ALTERNATIVE TO HIGH ACCURACY MERCURY COLUMNS
- RANGES FROM 10 kPa TO 1 MPa



INTRODUCTION

DH-BUDENBERG has always been dedicated to offering highest level accuracy pressure standards to its customers, hence it has reached its reputation in the pressure metrology field. French pioneer in this activity, DH-BUDENBERG is nowadays the world's number 1 supplier of primary pressure standards.

More than 50 countries on the 5 continents rely on DH standards for their pressure measurements. 47 national laboratories - including NIST in the USA, PTB in Germany, NRLM in Japan, LNE in France - have selected D&H to create their National Calibration Chain.

UNIQUE APX50 CHARACTERISTICS

The APX50 pressure balance was chosen by the BNM-LNE over mercury manometer because its high-level technology brings the following advantages:

- achievable uncertainty on generated pressure is improved by a ratio of 2 to 3 over mercury manometer,
- primary fully automatic pressure standard,
- unique rotative system of the piston-cylinder assembly providing high sensitivity without any interference,
- sources of uncertainty are less important and more easily measured and monitored (no need for complex temperature regulation/monitoring, no meniscus and parallax problems, less external environment influences),
- no need for harmful fluid such as mercury,
- operation is faster thanks to quick pressure stabilization time (pressure setting and measurements take 1 to 2 minutes),
- measurements can be toggled between gauge and absolute pressures within minutes,
- measuring principle is fully coherent with pressure standards used for measuring higher pressures, and which are pressure balances as the APX50, therefore reducing uncertainties in crossfloating,
- extra large piston-cylinder assembly whose area can be determined from true dimensional measurement.

MEASUREMENT PRINCIPLE

The APX50's measuring principle is based on the fundamental equation of pressure $P = F/A$ with:

- P as the measured pressure, expressed in Pa,
- A as the perfectly well-known piston-cylinder assembly effective area expressed in m^2 ,
- F as the force (in N) created by masses (in kg) submitted to gravity (in $m \cdot s^{-2}$) and applied to the piston.

As the masses M are determined through direct intercomparison with Standard Masses and the piston-cylinder assembly area A is directly measured with a laser interferometer, the measured pressure value then directly derives from the primary quantities of mass, length and time. Consequently, the APX50 pressure balance is recognised as a primary pressure standard.

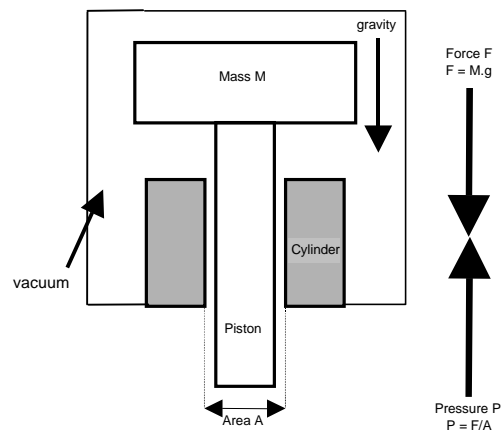
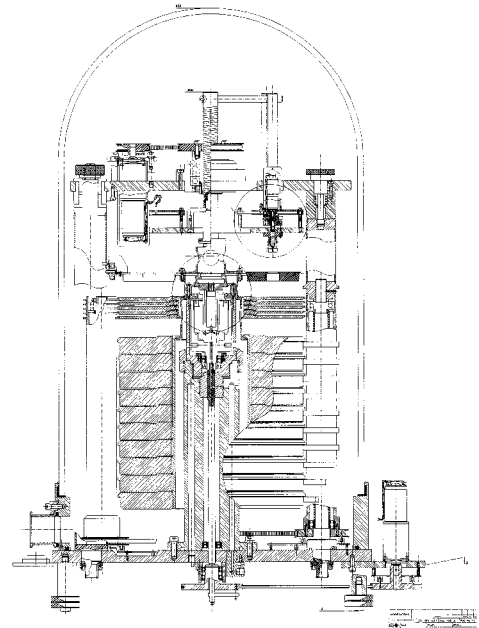
For the measurement of absolute pressure, the top of the piston and the masses are placed under vacuum. When the top of the piston and the masses are placed under ambient pressure, the APX50 allows gauge pressure measurements.

PRESSURE CALCULATION

The French National Laboratory for pressure quantity BNM-LNE (Paris - France) consulted our company in 1993 in order to start the definition and study of a prototype for a new national absolute reference to be operated in a range from 10 kPa to 1 MPa.

The aim of the project was to reach uncertainty level of 10^{-6} with the originality of using well-known large effective area piston/cylinder and having a fully automatic system with, for the first time with a pressure balance, automatic mass loading under vacuum.

The APX50 absolute pressure balance is the result of this joined cooperation between the BNM-LNE and DH-BUDENBERG.



The pressure measured by the APX50 is calculated according to the following formula:

$$P_A = P_{\text{vacuum}} + \frac{M_A g_l}{A(1 + (\alpha_p + \alpha_c)(t - 20))(1 + \lambda P)}$$

The APX50 pressure balance is designed in such a way that all the parameters of this equation are fully monitored so that maximum performance can easily be achieved.

Masses

They are made of austenitic, amagnetic type 304L stainless steel and their value is in kg, which is the SI quantity for masses.

They are hanged over the piston to curb side-effects and side forces.

The complete set consists of main masses (9 masses of 10 kg), divisional masses (5 masses of 2 kg and the mass loading bell), and fractional masses (masses from 1 to 2047 g with binary evolution) which can be combined in anyway to give a resolution as good as 10 ppm over the full range.

Piston-cylinder assembly

It is made of tungsten carbide which is the material that offers the best machining possibilities, and the best metrological specifications among which are:

- roundness, straightness and parallelism within 0.1 μm
- clearance between piston and cylinder of 0.4 μm
- sensitivity better than 0.1 ppm
- thermal expansion coefficient of 9 ppm / $^{\circ}\text{C}$
- pressure distortion coefficient of 4.10^{-9} kPa $^{-1}$
- Young's modulus of $6 \cdot 10^{11}$ N/m 2

SYSTEM CONFIGURATION AND ACCESSORIES

The standard configuration of the APX50 automatic primary pressure standard is composed of:

- 1 APX50 pressure balance with automatic mass loading system under bell.
- 1 tungsten carbide piston-cylinder assembly with a nominal diameter of 35 mm, and a nominal effective area of 10 cm 2 .
- 1 mass set of total value 100 kg with smallest incremental mass of 1 g, with full automatic changeover under vacuum, from 0.95 kg to 100 kg, by steps of 1 g within seconds.
- 1 bell jar.
- 1 command interface to execute remote mass loading.
- 1 optical piston position sensor.
- 1 MS-Windows-based command software package to command mass loading through the command interface.
- 1 IBM compatible computer P200 to host supplied software (optional).
- 1 capacitive vacuum sensor to measure residual pressure in the vacuum chamber.
- 1 molecular vacuum pump to establish reference vacuum.
- 1 pressure control automatic or manual rack (as requested) to apply pressure points to the pressure balance and to the instrument under test.
- 1 platinum resistance thermometer.
- 1 double stage vacuum pump to establish test pressure points below atmospheric pressure.

CALIBRATION

Calibration will be performed by the BNM-LNE French National Laboratory.

Area calibration

The piston-cylinder assembly area will be determined by direct measurement with a laser interferometer dimensional measurement bench. Measurements of diameters, straightness and roundness will be made both on the piston and cylinder, in various plans and sections.

The uncertainty that can be achieved depends on the geometry of the piston and cylinder and will range from $2 \cdot 10^{-6}$ to $4 \cdot 10^{-6}$ of value with $k=2$.

Mass calibration

The value of the masses will be determined by direct intercomparison with the French National Standards. The uncertainty will be $1,5 \cdot 10^{-6}$ with $k=2$.

Uncertainty on pressure measurement

The achievable uncertainty on pressure measurement is the sum of the uncertainties on mass value and piston-cylinder area value. It will range from $\pm(0,1 \text{ Pa} + 3 \cdot 10^{-6} p)$ to $\pm(0,1 \text{ Pa} + 5 \cdot 10^{-6} p)$ with $k=2$.

Additional sources of uncertainty will come from the monitoring and correction of environmental influences. Under normal laboratory conditions and using the built-in environmental monitoring facilities, environment influence may bring an additional 1 to 2 ppm of reading to the uncertainty on pressure.

METROLOGICAL SPECIFICATIONS

The APX50 automatic primary pressure balance has the following metrological specifications:

Pressure range:	10 kPa to 1 MPa absolute and gauge 2.95 inHg to 295 inHg absolute and gauge
Minimum pressure step:	10 Pa
Sensitivity:	better than 0.1 ppm
Stability:	better than 1 ppm/year
Repeatability:	better than $3 \cdot 10^{-6}$ of reading from 100 kPa
Readout resolution:	10 Pa 0.002953 InHg
Resolution of capacitive sensor:	0.01 Pa
Pressure units:	inHg, psi, kPa, Torr, inH ₂ O, mbar, altitude, mmH ₂ O, bar, MPa, kg/cm ² and one user defined unit
Operating pressure medium:	clean and dry gas, e.g. nitrogen

OTHER TECHNICAL SPECIFICATIONS

Dimensions:	height < 100 cm width < 70 cm depth < 70 cm weight \approx 200 kg
Power requirements:	220 V AC
Other requirement:	a nitrogen supply at 1.1 MPa, a bench, a hanging system to lift the bell

If you require more details about the APX50, or a demonstration, please consult us. D&H is also providing full assistance for on-site installation and complete training on the APX50.

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DH-BUDENBERG SA
56, rue des Ecoles - BP 125
93303 Aubervilliers Cedex
FRANCE
Téléphone : 33 (0) 1 48 39 83 00
Téléfax : 33 (0) 1 48 33 65 90
E-mail : dhonline@desgranges.com

DH-BUDENBERG LTD
PO BOX 224, Woodfield Road
Altrincham, Cheshire WA 14 4FY
UNITED KINGDOM
Telephone : 44 (0) 161 942 4700
Telefax : 44 (0) 161 942 4701
E-mail : sales@dh-budenberg.co.uk

DH-BUDENBERG GMBH
Raiffelsenstrasse 2
D-63110 Rodgau
DEUTSCHLAND
Telefon : 49 (0) 6106/8294-0
Telefax : 49 (0) 6106/8294-17
E-mail : desgranges.support@t-online.de

www.dh-budenberg.com

APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

INTRODUCTION

French Pioneer of pressure metrology, Desgranges & Huot is nowadays the World's Number 1 supplier of Primary Pressure Standards.

More than 50 countries on the 5 continents rely on D&H standards for their pressure measurements ; 51 National Laboratories have selected D&H to create their National Calibration Chain.

Since the early fifties, D&H has been cooperating very closely with the French National Laboratory, today called BNM-LNE.

In 1993 the BNM-LNE consulted us in order to start the definition and study of a prototype for a new national absolute reference to be operated in a range up to 1 MPa.

The aim of the project was to reach uncertainty level of 10^{-6} with the originality of using well-known large effective area piston/cylinder and having a fully automatic system, with, for the first time on a pressure balance, an automatic mass loading system under vacuum.

The APX50 absolute pressure balance is the result of this joined cooperation between the BNM-LNE and Desgranges et Huot.

Full detail on the history of the project was issued in the 7th Congrès International de Métrologie of Nimes (France) in 1995, by Mr J.C.LEGRAS and Mrs J.LE GUINIO of BNM-LNE.

APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

TABLE OF CONTENTS

1. Introduction	3
2. The APX50 pressure balance.....	4
2.1. Engineering drawing.....	4
2.2. Photograph.....	5
3. Measurement Principle	6
4. Piston Cylinder Assembly	7
5. Measuring Post.....	8
6. Mass Set.....	8
7. Mass Loading System	9
8. APX50 & Environment Monitoring	9
9. Command & Application Software Package.....	10
10. Calculation of pressure	10
11. Calibration & Testing	11
<i>Dimensional Measurement by BNM-LNE Primary Length Laboratory</i>	<i>11</i>
<i>Mass Measurement by BNM-LNE Primary Mass Laboratory.....</i>	<i>11</i>
<i>Temperature Calibration of the PRT by BNM-LNE Temperature Laboratory.....</i>	<i>11</i>
<i>Pressure Calibration by BNM-LNE Primary Pressure Laboratory.....</i>	<i>11</i>
<i>Testing by BNM-LNE Primary Pressure Laboratory</i>	<i>12</i>
12. Other technical specifications	12
13. Accessories	12
14. System Requirements	14
15. Scope of supply	14
16. Recommended Spare Parts	15
17. On-Site Training Program.....	16
18. Statement of Country of Origin	17

APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

1. INTRODUCTION

The APX50 Automatic Pressure Balance has the following capabilities:

- Measuring principle: Primary
- Pressure range: 10 kPa to 1 MPa
- Achievable Uncertainty: Below 5 ppm of pressure reading
- Sensitivity: Better than 0.1 ppm
- Stability: Better than 1 ppm/year
- Repeatability: Better than 1 ppm
- Operation: Fully automatic, including mass loading under vacuum

Developed under cooperation with the French National Laboratory for pressure quantity BNM-LNE, the APX50 was first delivered in 1996 in order to replace mercury manometers and improve French National Standards.

It was chosen by BNM-LNE over mercury manometer because its straight forward technology brings the following advantages:

- Achievable uncertainty on generated pressure is improved by a ratio of two to three over mercury manometer
- Sources of uncertainty are fewer and easier measured and monitored (no need for complex temperature regulation/monitoring, no meniscus and parallax problems, fewer influence of external environment...)
- There is no use of dangerous material such as mercury
- Operation is faster thanks to a quicker pressure stabilisation time (pressure setting and measurements takes 1 to 2 minutes)
- Measurements can be toggled between gauge and absolute pressure within minutes
- Measuring principle is fully coherent with pressure standards used for measuring higher pressures which are also pressure balances, therefore reducing uncertainties in cross-floatations

The instrument perfectly fulfils those goals, and the unsurpassed level of performance achieved by BNM-LNE' APX50 was presented to the Metrology Sphere at the EUROMET mass meeting in Delft (Netherlands) in February 1997. Last results have been presented during the CCM conference in Torino (Italy) last May 99, by BNM-LNE, together with a presentation of all technical and mechanical aspects of APX50 by DESGRANGES & HUOT.

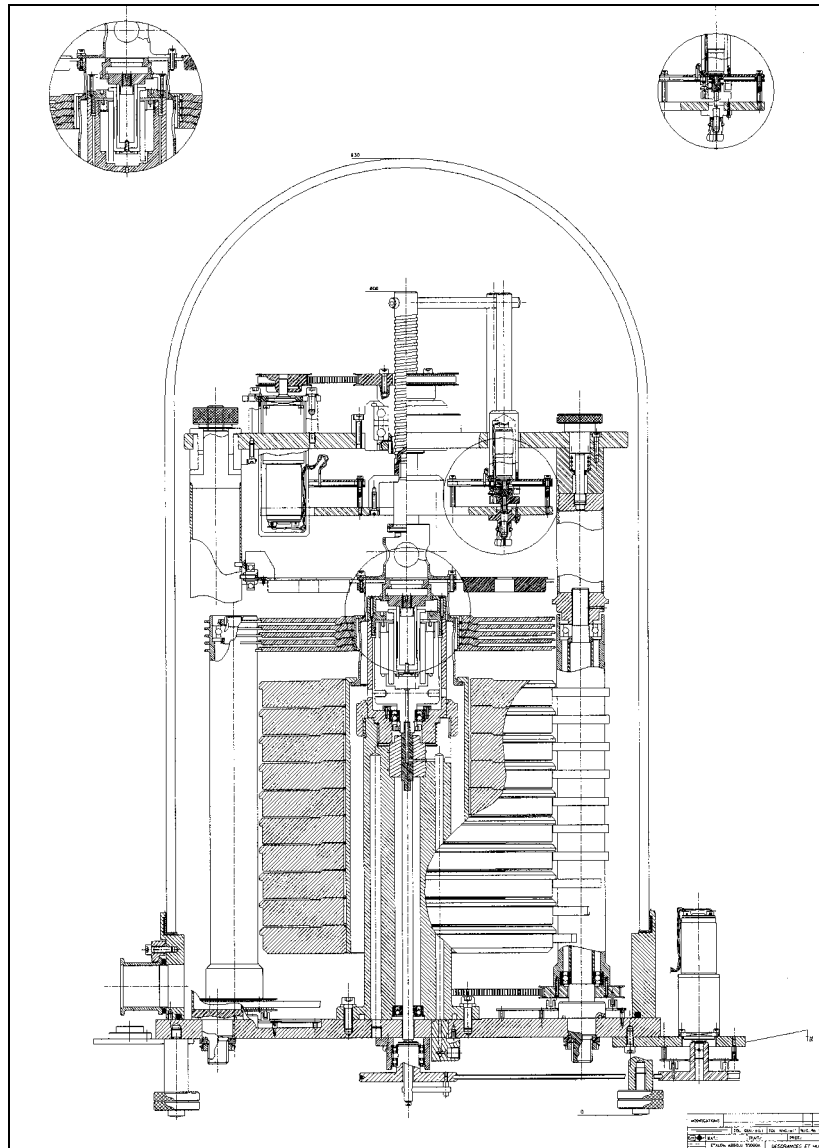
In 1999 BNM-LNE decided to procure a second unit in order to allow automatic piston-cylinder cross-floatation under vacuum. This second unit benefited from various technical improvements gained from the experience gathered on the first unit and was installed in December 1999.

APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

2. THE APX50 PRESSURE BALANCE

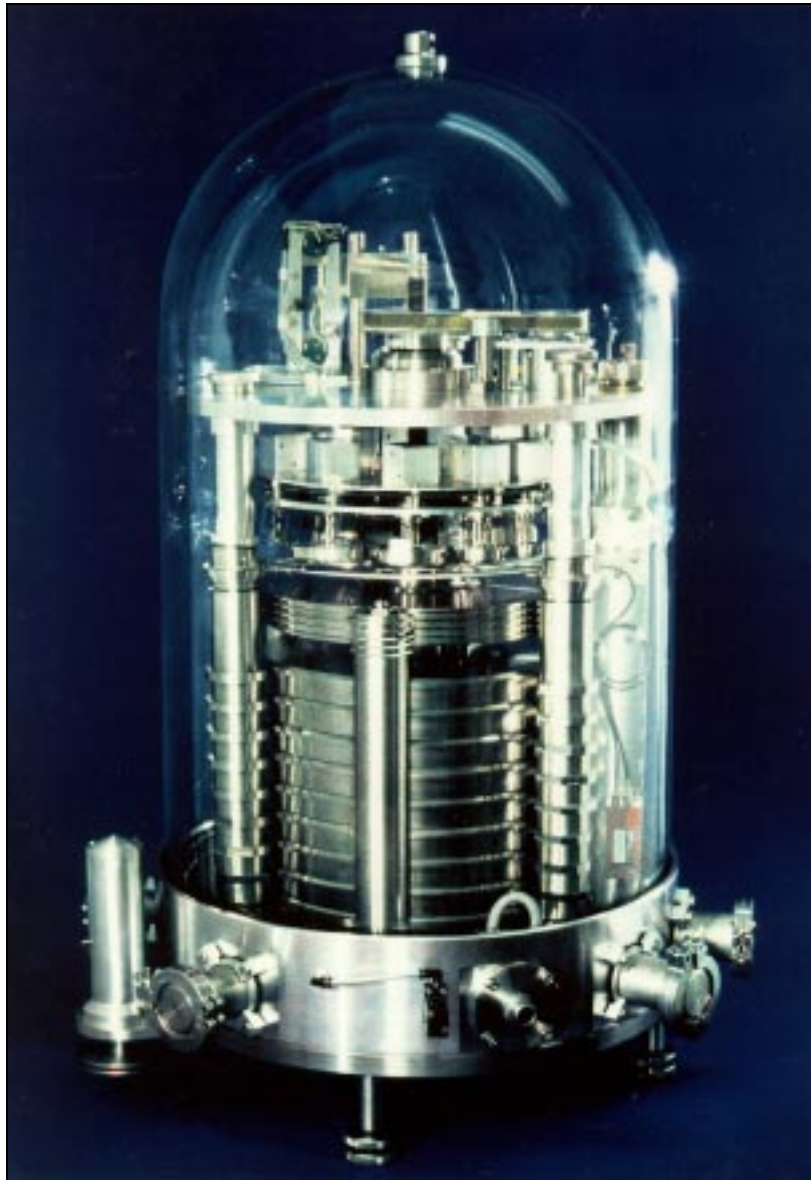
2.1. Engineering drawing



APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

2.2. Photograph

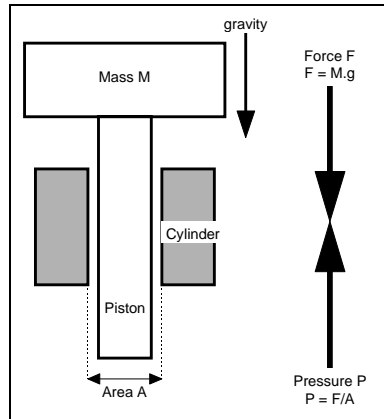


APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

3. MEASUREMENT PRINCIPLE

The APX50 is a pressure balance whose measuring principle is based on the fundamental equation of pressure $P = F/A$:



$$P = \frac{F}{A} = \frac{M \cdot g}{A}$$

with:

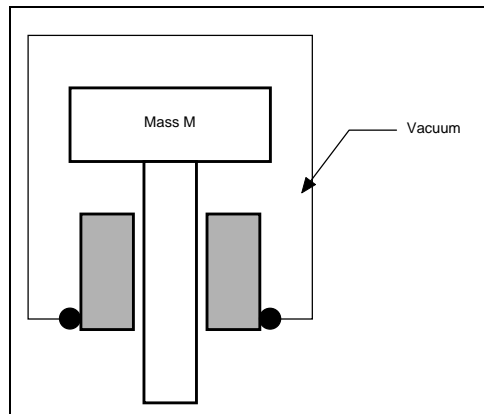
- P being the measured pressure, expressed in Pa
- A being the perfectly well known area of a piston cylinder assembly, expressed in m^2
- F being the force (expressed in N) created by masses (expressed in kg) submitted to gravity (expressed in $m \cdot s^{-2}$) and applied to the piston

As the masses M are determined through direct comparison with Standard Masses and the area A of the piston cylinder assembly is determined through direct measurement using laser interferometry, pressure measured by the APX50 is then directly derived from the primary quantities of mass, length and time, and the APX50 is recognised as a true primary pressure standard.

APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

For the measurement of absolute pressure, the top of the piston and the masses are placed under vacuum in a bell Jar which is evacuated:



Pressure measurements are then referenced to vacuum and are absolute pressure measurements.

When the top of the piston and the masses are left under ambient pressure, the model APX50 pressure balance allows the measurement of gauge pressures.

4. PISTON CYLINDER ASSEMBLY

The APX50 Piston-Cylinder Assembly (PCA) benefits from Desgranges & Huot's 55 years expertise gained in manufacturing Pressure Standards for National Metrology Institutes. It offers performance levels that no other make of piston cylinder can achieve.

Features include:

- Full tungsten carbide construction
- Effective area: 10 cm² giving a pressure to mass conversion coefficient ("Kn") of 10 kPa/kg
- Near perfect geometry with typical roundness, straightness and parallelism within 0.1 μm
- Clearance between piston and cylinder of circa 0.4 μm
- Sensitivity better than 0.1 ppm
- Float times exceeding 30 minutes at full load
- Free spinning time exceeding 15 minutes at full load
- Thermal expansion coefficient of 9 ppm.°C⁻¹
- Pressure distortion coefficient of circa 0.85 10⁻⁸.kPa⁻¹
- Young's modulus of 6.10¹¹ N/m²
- Titanium piston head
- Piston mass: 500 g

APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

5. MEASURING POST

The APX50 PCA is hosted in a very novel measuring post designed to operate smoothly the PCA, without interference, hence allowing achievement of superior levels of metrological performance.

The APX50 measuring post features:

- Simple free deformation mounting principle
- Floating piston with rotating cylinder
- Motor driven cylinder rotation from external motor, with adjustable speed and direction

6. MASS SET

Uniquely, the mass set of the APX50 is made of a rigorously non-magnetic Alloy (Arcap) which allows determining the value of each mass with uncertainty levels previously never achieved in the field of pressure balance metrology.

The APX50 masses feature:

- Full Arcap (Nickel / Copper / Zinc Alloy) plain and non-adjustable construction with orange skin finish
- Magnetism: $< 0.000\ 001$ Oersted (i.e. $< 7.95\ 10^{-5}$ A.m⁻¹)
- Density: 8,800 kg.m⁻³
- Total mass set: 102,047 g
- Start mass: 950 g (including piston mass)
- Smallest individual loadable mass (mass resolution): 1 g
- Mass set organisation: divided in three sub-sets (Main Set, Divisional Set and Trim Set)
- Trim mass set construction: binary progression from 1 g to 1,024 g
- Divisional mass set construction: 5 masses of 2 kg
- Main mass set construction: 9 masses of 10 kg
- Manufacturing tolerance of trim masses from 1 to 64 g: ± 1 mg
- Manufacturing tolerance of trim masses from 128 to 512 g: ± 5 mg
- Manufacturing tolerance of all other masses: $\pm 5.10^{-5}$ of value

APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

7. MASS LOADING SYSTEM

Uniquely, the APX50 pressure balance features automatic changeover of masses under vacuum: any mass value can be automatically loaded on the piston under vacuum from 950 to 102,997 g by steps of 1 g. This unique feature not only facilitates and accelerates the operation of the instrument, but mainly maximises achievable uncertainty level by maintaining perfectly stable reference conditions.

The automatic mass loading system consists in 3 sub-systems, one for the Main 10 kg Masses, one for the Divisional 2 kg Masses, and one for the Trim Mass Set. Each sub-system operates independently and is commanded under computer control from a software package supplied with the APX50.

The APX50 is designed in such a way that the upper part of the mass loading system can swing aside in order to give full access to the measuring post within 1 minute.

The Mass Loading System features:

- Fully automatic mass changeover to 1 g resolution
- Automatic protection of the instrument under test during mass change-over
- Over-hang loading of the Main and Divisional Masses placing the centre of gravity below the Piston Cylinder Assembly, hence allowing a perfectly vertical Force
- Quincunx arrangement for the Trim Masses eliminating any imbalance of the mass load
- Independent mass loading systems for each Mass Set
- Non-interfering, "normally OFF" mass loading and unloading systems

8. APX50 & ENVIRONMENT MONITORING

The APX50 pressure balance is delivered with all monitoring facilities required to achieve the expected level of metrological performance:

- A built-in 4 wires Platinum Resistance Thermometer for measuring the PCA temperature located in the heart of the measuring post as close as possible to the PCA. Nominal resistance is 100 Ohms at 0°C. Temperature range is -50 to 220 °C. Accuracy class is "A" per CEI 751 standard (± 0.1 °C). The PRT can be easily removed for calibration.
- A built-in optical Piston Position Sensor for the precise determination of the piston height and movements with accuracy of ± 0.01 mm and sensing time below 1 ms.
- A built-in Cylinder Rotation speed and direction control and measurement within ± 1 rpm.
- Levelling Feet and built-in high accuracy Spirit Level for precisely adjusting PCA verticality.
- A DH-Budenberg Terminal 5000 interface with built-in Environment Monitoring Module for air buoyancy correction when operating the APX50 in gauge mode. T5000 measures ambient temperature to ± 0.2 °C, air moisture to $\pm 5\%$ and ambient pressure to ± 5 hPa.

All command and environment monitoring electronics is external to the APX50, hosted in one rack and one terminal, for eliminating any risks of static charge, heat, and other electronics-related interference within the APX50.

APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

9. COMMAND & APPLICATION SOFTWARE PACKAGE

The APX50 pressure balance is delivered with a comprehensive MS-Windows based software package which allows:

Command Functions

- Full command and control over the APX50 and its accessories
- Execution of all maintenance and service related routines

Pressure Calibration Functions*

- Cross-floatation of dead-weight testers and pressure balances
- Automatic calibration of high accuracy digital gauges
- Automatic calibration of transducers, transmitters, calibrators...
- Programming of calibration cycles, pre-set, discrete, repeated
- Calculation of DUT specifications; print-out and storage of calibration certificates
- Transfer of test results to Microsoft Excel or Lotus 1-2-3 for custom processing

(* Some functions are under development)

10. CALCULATION OF PRESSURE

The pressure measured by model APX50 pressure balance is calculated with the following formulae:

$$P_A = P_{Vacuum} + \frac{M_A g_l \left(1 - \frac{\rho_a}{\rho_M} \right) + \Gamma \pi C}{A (1 + (\alpha_P + \alpha_C)(t - 20))(1 + \lambda P)}$$

where:

- I. P = Measured pressure in Pa
- II. P_{vacuum} = Remaining pressure in reference vacuum in Pa (applies only in absolute pressure mode)
- III. M_A = Mass loaded on the piston (absolute value, referenced to vacuum) in kg
- IV. g_l = Local gravity in $m.s^{-2}$
- V. ρ_a = Density of air under the bell jar in $kg.m^{-3}$ (0 if under vacuum)
- VI. ρ_m = Density of the metal from which the masses are made in $kg.m^{-3}$
- VII. Γ = Surface tension of the pressure medium in $N.m^{-1}$
- VIII. C = Circumference of the piston in m
- IX. A = Effective area of the piston cylinder assembly as given in the calibration certificate, in m^2

APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

- X. α_C = Thermal expansion coefficient of the cylinder in $^{\circ}\text{C}^{-1}$
- XI. α_P = Thermal expansion coefficient of the piston in $^{\circ}\text{C}^{-1}$
- XII. t = Temperature of the piston cylinder assembly in $^{\circ}\text{C}$
- XIII. λ = Pressure distortion coefficient of the piston cylinder assembly in Pa^{-1}

The precise use of the above formulae is necessary in order to achieve the measurement specification. The model APX50 pressure balance is delivered with a micro-computer and a software package which performs the precise calculation of pressure using the environment monitoring facilities.

11. CALIBRATION & TESTING

As part of our cooperation agreement with BNM/LNE French National Laboratory, the APX50 is calibrated prior to delivery by BNM/LNE for the following:

Dimensional Measurement by BNM-LNE Primary Length Laboratory

- Piston Cylinder Assembly Diameter in 4 diameters
- Piston Cylinder Assembly Straightness for 4 generating lines in 2 perpendicular planes
- Piston Cylinder Assembly Circularity in 5 planes

Measurements are done with laser interferometry.

Expected uncertainty is 3 to 5 ppm with $k=2$.

A calibration certificate is issued

Mass Measurement by BNM-LNE Primary Mass Laboratory

All masses from 1 g to 10 kg are weighed.

Expected uncertainty is 1 to 1.5 ppm with $k=2$.

Density of the various mass materials is determined.

A calibration certificate is issued.

Temperature Calibration of the PRT by BNM-LNE Temperature Laboratory

Pressure Calibration by BNM-LNE Primary Pressure Laboratory

- Pressure calibration at 10, 100, 200, 300, 400, 500, 600, 700, 800 and 1000 kPa and repeated 5 times

Expected uncertainty is 4 to 6 ppm with $k=2$.

A calibration certificate is issued.

The Primary Pressure Laboratory calculates the PCA effective area from the dimensional measurements and compare results with the area determined from pressure calibration.

APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

Testing by BNM-LNE Primary Pressure Laboratory

- Validation of the behaviour of the PCA under vacuum, including testing at 10, 50, 100 and 150 kPa absolute. This test is performed by installing the PCA in one of BNM-LNE's well known APX50 and cross-floating it with BNM-LNE's Primary Standard installed in BNM-LNE's other APX50. It includes pressure recording at each pressure point for 15 minutes.
- Measurement of residual pressure in vacuum under the bell jar when pumping with the vacuum pump supplied with the APX50.
- Control of the MKS Baratron™ Vacuum Sensor supplied with the APX50 by comparison with one of BNM-LNE's working sensors.
- Verification of the PCA verticality.

12. OTHER TECHNICAL SPECIFICATIONS

Vacuum connections: 6 each, DN 40

Pressure connection: DH1500 standard

Bell Jar: Mono-bloc Pyrex construction

Dimensions: Height < 100 cm
Width < 70 cm
Depth < 70 cm
Weight ≈ 200 kg

13. ACCESSORIES

For proper operation within expected metrological performance, the APX50 Pressure Balance requires the following accessories and services:

Tools: All tools required for set-up, installation, operation and first level maintenance

Spare Parts: All spare parts and consumables required for first level maintenance

Tubes and Fittings: One each test stand for the instrument under test with a set of 8 NPT and BSP adapters and all required fittings and tubing to connect the APX50 to the vacuum pumps, pressure controller and instrument stand.

Manual: Fully comprehensive installation, operation and first level maintenance manual

Vacuum Pumps: One each Alcatel model Drytel 100™ Molecular Pump, allowing evacuation of the jar below 2 Pa within 20 minutes, with Nominal flow of 100 m³.h⁻¹ and limit pressure of 5.10⁻⁴ Pa.
One each Edwards RV5 vacuum pump with 5 m³.h⁻¹ evacuation capability for establishing test pressure points below atmospheric pressure.
Vacuum Piping and connections are included.

APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

Pressure Controller:	One each DH-Budenberg Model GPC2-A025 automatic pressure controller allowing to set test pressure automatically under command of the Operating Software. Piping and connections are included.
Command Interface:	One each APX50 command interface.
Ohm-meter:	One each Ohm-meter for the measurement of the PCA PRT.
Vacuum Sensor:	One each model 690A MKS Baratron™ Vacuum Sensor with 670B Digital Interface for the measurement of residual pressure under the bell jar with an accuracy of 0.08% of reading.
Differential Sensor:	One each model 698A MKS Baratron™ Differential Pressure Sensor with 670B Digital Interface allowing precise cross-floatation of a pressure balance against the APX50.
Computer:	One each IBM compatible personal computer with Intel Pentium processor, 32 megabytes of RAM, 2 gigabytes of hard disk, 15" screen, keyboard, mouse, 8x CD-ROM player, floppy disk drive, MS-Windows, MS Office, to host supplied software packages.
Bench:	One each granite bench on which is to be installed the APX50.
Cabinet:	One each cabinet in which are racked the Pressure Controller, the Ohm-meter, the Command Interface and both MKS 670B™ Digital Interfaces.
Hoisting gear:	One each electrical hoisting gear with 50 kg capability to easily lift the Bell Jar
Compressor:	One each model 6M Jun'Air compressor with 32 l.m ⁻¹ flow rate and 600 kPa nominal output pressure (1 MPa maximum) to supply drive air pressure to the test circuit isolation valve, the MKS 690A™ isolation valve, and the vent valve.
On-site Installation:	7 working days installation, training and start-up, performed by two D&H experts at end-user site
Initial Training:	2 working weeks initial commissioning and training at DH-Budenberg Paris Factory for 2 persons, prior to delivery.

APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

14. SYSTEM REQUIREMENTS

The APX50 Pressure Balance requires:

- Electric Power: 220 V AC or 110 V AC (To be specified)
50 or 60 Hz (To be specified)
Total system consumption is 2.5 kW
- Test Pressure: A clean and dry gas supply (e.g. Nitrogen) at 1.1 MPa
- Benches: A table on which will be installed the command computer
A bench to support the Device Under Test

To achieve full performance the APX50 must be installed in a temperature controlled laboratory conforming to ISO Guide 25 standard.

The height of the laboratory ceiling must be 3.2 m minimum to give sufficient room for lifting the bell jar with the hoisting gear. The ceiling must be equipped with a hook precisely located above the APX50 pressure balance for installing the hoisting gear.

15. SCOPE OF SUPPLY

The APX50 base supply consists in:

- The APX50 Pressure Balance with
 - One each complete 102,047 g Arcap Mass Set
 - One each 10 cm² PCA
 - All built-in features and accessories including PRT and Position Sensor
- The APX50 Command Interface
- The APX50 Command Software Package
- The Terminal 5000
- The Ohm-meter
- The Vent valve, Test isolation valve and Vacuum sensor isolation valve
- Standard accessories, spares, tools and manuals
- All Calibrations and Testing at BNM-LNE as described
- The 7 working days on-site installation, training and start-up

APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

Optional supplies are:

- The MKS Baratron™ vacuum sensor and its interface
- The MKS Baratron™ differential sensor and its interface
- The Alcatel Molecular Vacuum Pump
- The Edwards RV5 Double Stage Vacuum Pump
- The DH-Budenberg GPC2-A025 Automatic Pressure Controller
- The test stand for the instrument under test with adapters
- All additional spares, accessories, tubing and fittings as described
- The Personal Computer
- The Granite Bench
- The Cabinet for housing electronic racks
- The Hoisting Gear
- The drive air Compressor
- The 2 working weeks Initial Training prior to delivery

16. RECOMMENDED SPARE PARTS

All spare parts and tooling suitable for start-up, operation and first level maintenance of model APX50 pressure balance are included in the original delivery.

It is recommended that the end-user procures a spare Pyrex Bell Jar.

There is no list of additional recommended spare parts or tools.

APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

17. ON-SITE TRAINING PROGRAM

The APX50 comes with a 7 days start-up and training for the institute personnel. Training is performed by two of our expert engineers fluent in English.

Program is as follows:

Day 1 (Equipment Set-up)

Morning: Unpacking of equipment

Afternoon: Set-up of the equipment

Day 2 (Equipment Set-up)

Morning: Set-up of the equipment

Afternoon: Set-up of the equipment

Day 3 (Test and description)

Morning: Operation testing

Afternoon: Operation testing

Day 4 (The model APX50 Pressure Balance)

Morning: Operating model APX50 Pressure Balance

Afternoon: Operating model APX50 Pressure Balance

Day 5 (The model APX50 Pressure Balance)

Morning: Study of LNE calibration certificates

Afternoon: Study of LNE calibration certificates

Day 6 (The calibration of Pressure Instrument)

Morning: Calibrating a pressure instrument with model APX50 pressure balance

Afternoon: Calibrating a pressure instrument with model APX50 pressure balance

Day 7 (The maintenance of APX50 Pressure Balance)

Morning: The first level maintenance of model APX50 pressure balance

Afternoon: The first level maintenance of model APX50 pressure balance

APX50 Automatic Absolute Pressure Balance

Project for the supply of A Primary Absolute Pressure Standard

18. STATEMENT OF COUNTRY OF ORIGIN

The Model APX50 Automatic Pressure Balance is an instrument designed in cooperation with BNM-LNE (Paris – France) and manufactured by:

DH-BUDENBERG SA
56 rue des Ecoles
93300 Aubervilliers
France
Tel +33 1 48 39 83 00
Fax +33 1 48 33 65 90

A Société Anonyme organised under the Law of France with a share capital of
13 500 000 FRF

The Model APX50 Automatic Pressure Balance is a product of France origin.

**APX50: A NOVEL FULLY AUTOMATIC ABSOLUTE PRESSURE BALANCE
AS A PRIMARY REFERENCE IN THE RANGE 10 kPa TO 1 MPa**

Presenter: Luc Dargent
Desgranges & Huot
56 rue des Ecoles
93300 Aubervilliers
France
Phone: +33 1 4839 8300
Fax: +33 1 48 33 6590
E-mail: dhonline@desgranges.com

Authors: Luc Dargent, Frédéric Poirier
Desgranges & Huot

1. Abstract

Traditional absolute pressure balances are designed so that the piston cylinder assembly and the masses are placed under vacuum in a bell jar. This makes their operation tedious and time consuming as the measurement of each new pressure value requires to return to barometric pressure, manually change the mass value and then evacuate the jar again.

This paper presents a novel design of absolute pressure balance where the handling of masses is fully automated, thus enabling the change of pressure within minutes with no need to break vacuum.

The instrument covers a pressure range of 1 MPa using a very large area piston cylinder assembly and a 100 kg mass set with 1 g resolution giving a pressure resolution of 10 Pa. Its uncertainty is estimated to ± 3 ppm of pressure reading.

It was developed in cooperation with the BNM-LNE French National Laboratory and is the new French National Standard for absolute pressure.

2. Primary Pressure Standards

Pressure (Pa) is a secondary physical quantity which derives from the primary physical quantities of mass (kg), length (m) and time (s). In order to define this secondary quantity and provide reference measurement means, two technologies were developed over time whose measurement principles derive pressure directly from its definition: the manometer and the pressure balance.

Manometers consist in a tube containing a liquid of known density [Fig. 1]. Pressure is measured according to the equation $P = \rho \times g \times h$ where P is the measured pressure in Pa, ρ is the density of the liquid in $\text{kg}\cdot\text{m}^{-3}$, g is the local gravity in $\text{m}\cdot\text{s}^{-2}$ and h is the height of the liquid in the tube.

Manometers have reigned over primary pressure metrology over the 20th century. Over the years, their technology has been refined: use of ultra pure mercury as the liquid, thermal stabilisation of the column, use of laser interferometer to determine the height of the liquid...etc...; they allow nowadays to determine pressure with an expanded

uncertainty ($k=2$) of circa 10 to 15 ppm in absolute and gauge pressure modes. It seems, however, that this level of uncertainty forms a difficult limit to break because of the level of technology involved in and care required for its achievement.



Fig. 1: U Tube Manometer

Pressure balances – or piston gauges – are based upon the piston cylinder technology [Fig. 2]. Pressure is applied to the low end of a vertically mounted piston of known area and is balanced by the force generated by a known mass loaded on the top end of the piston. Pressure is measured

according to the equation $P = \frac{m \times g}{A}$ where P is

the measured pressure in Pa, m is the applied mass in kg, g is the local gravity in $\text{m}\cdot\text{s}^{-2}$ and A is the effective area of the piston cylinder assembly in m^2 . Although they were showing remarkable metrological qualities, pressure balances remained for a very long time confined to the extension of the pressure scale from the limited low pressure range measurable by manometers (typically below 350 kPa) to the full spectrum of pressures. This is because, although the pressure balance is a primary standard in theory, it remained impossible until recently to determine the effective area of the piston cylinder assembly by other means than through crossfloatation with another pressure standard; hence, the pressure balance was deriving its measurements from another pressure instrument and not directly from the primary physical quantities of mass, length and time. Only in the early 1980's, Desgranges & Huot of France undertook the design and manufacture of pressure balances using very large area piston cylinder assemblies (diameter 35 mm) whose area could be directly measured by the means of a dimensional measurement bench. Thanks to this technical breakthrough, pressure balances have been recognised over the past 20 years as true primary pressure standards, and are now challenging manometers for the determination of the pressure quantity. Indeed, some pressure balances allow to determine pressure with expended uncertainties ($k=2$) circa 5 ppm in the gauge pressure mode, up to 1 MPa.

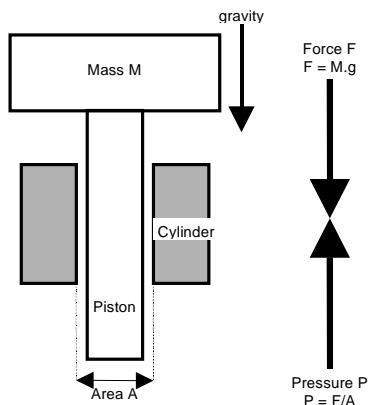


Fig. 2: Pressure Balance

However, the measurement of absolute pressure which is a natural domain for manometers, remains a difficult area for pressure balances. This requires to put the balancing mass into vacuum so that

measurements can be referenced to vacuum. Masses of absolute pressure balances are then placed under a jar which is evacuated [Fig. 3]. Each time a new pressure is to be measured, the jar is returned to barometric pressure, lifted, the mass is changed, and the jar is evacuated again. Not only does this make the operation of absolute pressure balances tedious and time consuming, but it also limits the level of uncertainty that such instruments can achieve because reference conditions are changed for every new pressure measurement, and because pressure sequences cannot be repeated under equal conditions.

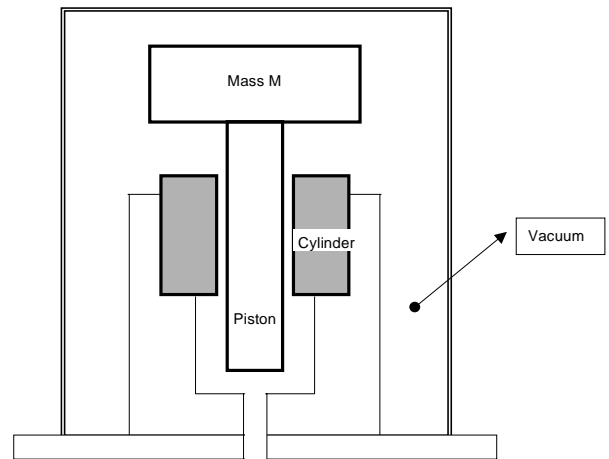


Fig. 3: Absolute Pressure Balance

On this basis, Desgranges & Huot and the French National Laboratory for Metrology – BNM-LNE – entered in 1993 into an agreement for the development of a new absolute pressure balance that would use well known large area piston cylinder assemblies (PCA) and have automated mass loading. Ultimately the aim was that the instrument could achieve an uncertainty level on generated pressures of 10^{-6} so that the new pressure balance could serve as the French National Standard for absolute pressure and eventually replace liquid column manometers.

This ambitious project was carried out in two main stages:

The first step consisted in developing a prototype using a large diameter PCA but with manual mass loading in order to validate the innovative design of the measuring post and some other technical choices.

The second step consisted in designing and manufacturing the automated version.

Named APX50, this new instrument [Fig. 4] was completed and installed at BNM-LNE in the end of 1996. After two and a half years of operation, it has now proven being fully operational and it perfectly meets the original scope of the project.

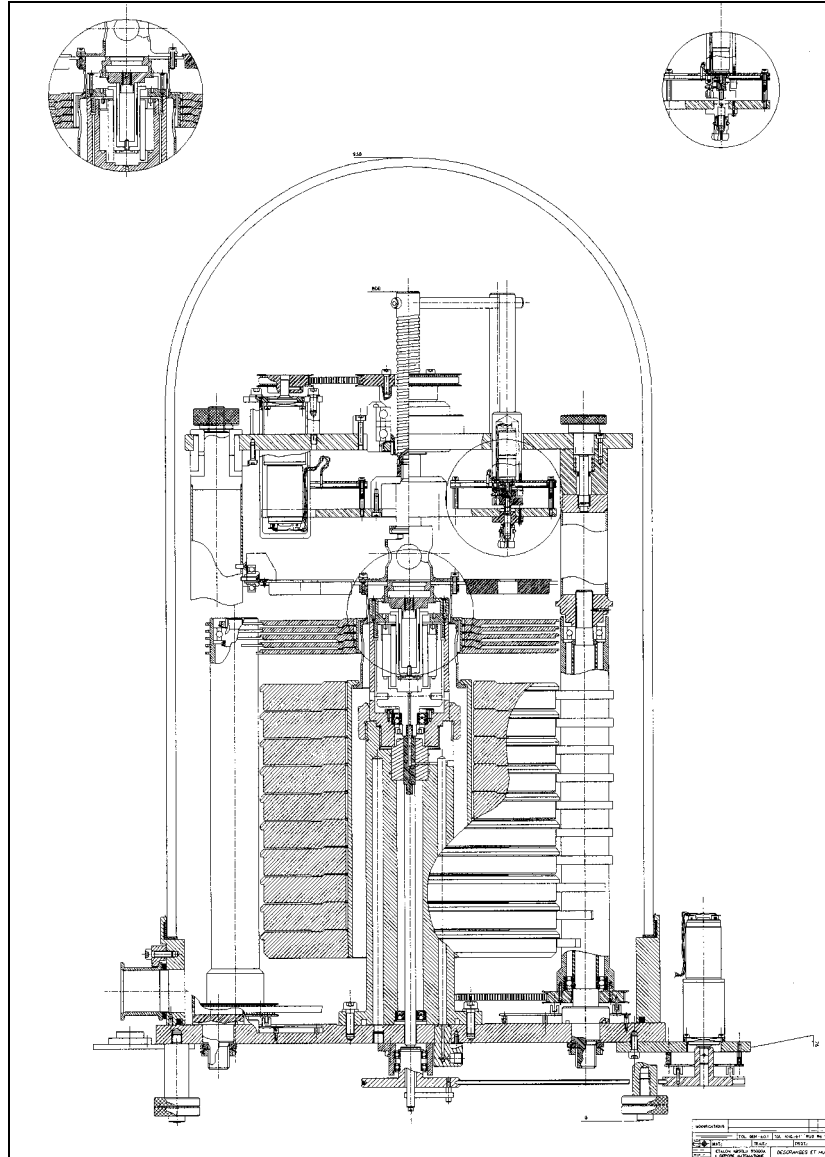


Fig. 4: The APX50 Automatic Absolute Pressure Balance

3. General Description of the APX50

The APX50 is an absolute pressure balance made of large effective area (10 cm^2) tungsten carbide PCA. This PCA is combined with a 100 kg mass set with fractional masses down to 1g. This combination gives a pressure range of 10 kPa to 1MPa, and a resolution of 10 Pa. The PCA and mass set are located under a bell jar which is evacuated to vacuum, so that pressure measurement can be referred to vacuum. The originality of the system is that the APX50 has a fully automated mass loading system which operates under vacuum. The loading and unloading of masses is automated throughout the full mass range.

4. Detailed Technical Aspects of the APX50

The first automatic pressure balances were gauge pressure balances developed in the early 80's to fulfil needs raised by some industries having massive pressure calibration requirements at the 50 ppm level. However, the experience gained on this generation of system was of little help for the development of the APX50 as the operation under vacuum is a source of mechanical restrictions and problems, and because the aimed uncertainty was 50 times better. All new features and technical aspects of the APX50 are detailed hereafter in this respect.

4.1. Measuring Post

The piston cylinder assembly is a 10 cm² PCA, used initially by BNM-LNE on a gauge transfer standard (Desgranges & Huot model 5111) for round-robin exercises and whose intrinsic performance is very well known because it has many years of measurement history.

The PCA is mounted in a special measuring post [Fig. 5] where the cylinder is rotating.

In order to limit the leaks that could come from moving parts, the cylinder rotation is made with the help of a rotating cylinder support which is ended by a shaft that goes throughout the base of the APX50. The shaft is rotated with the help of an electric motor – external to the vacuum jar – via a driving belt. This electric motor is located outside of the pressure balance in order to avoid any temperature effect within the bell jar.

A novelty of the APX50 is that the airtightness of this moving part is guaranteed by an auxiliary piston cylinder assembly: the top part of the shaft is in fact a piston and goes through a cylinder. The very small clearance of this primary standard style auxiliary piston cylinder assembly limits leaks to undetectable levels.

Finally, the lubrication of the measurement PCA is effected by means of the measured pressure.

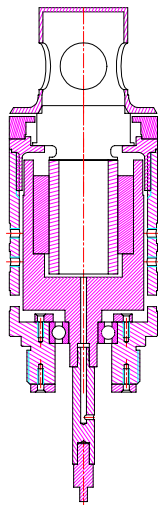


Fig. 5: APX50 Measuring Post

As mentioned before, the PCA is made of tungsten carbide. Its head is made of titanium (TA6V) in order to get a lighter weight and integrates a special hooking system.

This hooking system supports different elements. Firstly, it has a direct link to the fractional mass plate. Secondly, it can lift under certain circumstances the three different mass carrying bells of the APX50.

Therefore, both the hooking system and the fractional mass plate are part of the piston head, and the total mass of the piston is 950 g.

4.2. Mass Set

The mass set is of 102.997 kg total value. It is composed of main masses, divisional masses, fractional masses, mass carrying bells and finally the full piston mass.

As mentioned before, the APX50 has three different mass carrying bells [Fig. 6]: the main carrying bell which supports the main masses, the medium carrying bell which supports the divisional masses, and finally a transfer carrying bell which provides the link between the piston head hooking system and the medium carrying bell. This transfer carrying bell is interdependent of the medium carrying bell.

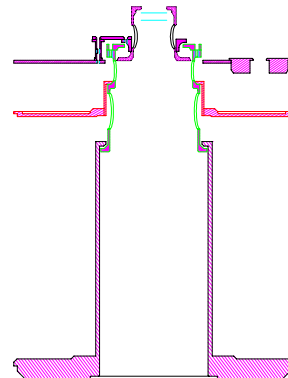


Fig.6: APX50 Mass Bells

Uniquely, masses are made of a nickel/copper/zinc stainless alloy which has magnetism below 10⁻⁶ Oersted, hence allowing determining their value with uncertainty of a few 10⁻⁷. The main and medium carrying bells are made of the same alloy. The fractional masses support plate is made of duralumin. All density values have been determined by BNM-LNE.

There is a total of nine main masses [Fig. 7]. The eight upper masses have a nominal value of 10 kg; the lowest one has an individual lower value but is linked with the main carrying bell and the total nominal mass of this ninth mass and the main carrying bell is 10 kg.

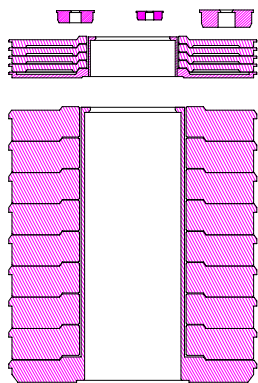


Fig. 7: APX50 Mass Set

There is a total of five divisional masses. The four upper masses have a nominal value of 2 kg, the lowest one has an individual lower value but is linked with the medium and transfer carrying bells and the total nominal mass of this fifth mass and the two carrying bells is 2 kg.

Finally, there is a set of fourteen fractional masses installed on a plate. Those masses have binary progression from 1 g up to 512 g and a total value of 2047 g. They are installed in quincunx on the plate and when they are used, they are selected two by two and on opposite sides in order to minimize any imbalance [Fig. 8].

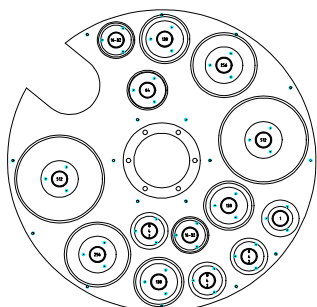


Fig. 8: APX50 Trim Masses

4.3. Automatic mass loading system

A main novelty of the APX50 lies also in its original automatic mass loading system. This mass loading system is operating all masses down to the 1 g mass.

The mass selection sequence is programmed so that the APX50 will select the masses that should not be in contact with the carrying bells or support plate in order not to create a force on the PCA. The mass selection sequence is always following the same procedure, starting first with the fractional masses selection, the divisional masses and finally the main masses.

The fractional masses have also an original selection system. Each fractional mass has a hole in its centre, and is supported by a plate. This plate is moved up and down with the help of an endless screw. Above each fractional mass, there is a hooking system made of a triple hook. In order to lift a fractional mass, the plate is lifted up by the endless screw, and when the triple hook is going through the mass hole, it opens, so that the mass remains lifted. Once this operation is done, the plate is brought down again. All fractional masses that remain on the plate will therefore be selected for pressure measurement as they will apply their force on the PCA.

The opening and closing of the hooks is activated by fourteen electro-magnets. In order to avoid any thermal or magnetism problems, those electro-magnets are off when opened and on only when closed. The closed status takes only a few seconds corresponding to the time for the fractional mass support plate to move up.

The endless screw mentioned above is actioned by a notched belt via an electric motor.

For the operation of the five divisional masses, three columns are placed at 120° around the divisional mass set. The three columns have 5 cams each, and each column can be positioned at five different angles. When a mass value has to be loaded, the columns are turned a few degrees so that the appropriate cams go below the required mass and select it. The lifted mass is maintained on three cams for safety and stability. The result is that the masses not lifted by a cam will therefore be in contact with the carrying bell and apply a force on the whole carrying system linked to the piston.

The same principle is used for the operation of the nine main masses: three columns are placed at 120° around the masses and at 60° of each of the three "divisional" columns. Each column is supporting 9 cams each, and each column can be positioned at nine different angles. When a mass value has to be loaded, the same sequence is applied as for the divisional masses.

The six columns are rotated by two separate belts on their bottom part which are activated by an electric motor which is located at the bottom of the instrument. The selection of a mass value is following a specific procedure, and a sequence takes 30 to 60 seconds.

It is important to mention that all the electrical motors used for the mass loading or unloading sequences are only activated for a few seconds and are always in an off position when pressure measurement is made.

5. The Pressure Balance

5.1 The Base

The base is a metallic support that receives the vacuum bell jar, the mass set and all the mass loading arrangements. It has six DN40 vacuum outlets for connection of support instrumentation and accessories such as vacuum pump, reference vacuum sensor, flow controller, vent solenoid valve...etc... It supports the external driving motor that drives the shaft for cylinder rotation and has four levelling feet and a level indicator.

The pressure measurement connection is located under the base.

The base of the APX50 has minimum on-board electronics in order to avoid any thermal, electrical or magnetic interference. All electronics are hosted in an external interface that receives and executes the commands received from the control computer.

A 4 wires platinum resistance thermometer is installed inside the PCA mounting post, as close as possible to the PCA, in order to monitor the PCA temperature.

A highly linear, repeatable and sensitive optical position sensor monitors the movements and position of the piston. The piston position detection point is the edge of the fractional mass support plate.

5.2 The Bell Jar

The bell jar is made of a mono-bloc Pyrex glass. The absence of any seals makes it fully airtight. Due to the weight of the jar, a hook located on its top allows lifting it up with a hoist.

When the bell is lifted up, it is possible to easily unscrew the top part of the mass loading system in order to gain a direct access to the PCA. This operation may be done in a few minutes either for PCA cleaning or substitution.

5.3 Accessories

A molecular vacuum pump is used for evacuating the bell jar and establishing reference vacuum. The vacuum pump provides a reference vacuum of 1 Pa in about 15 minutes. Within 30 minutes, reference vacuum will improve to a few tenths of a Pascal and kept for all measurements as, by principle, the APX50 does not require breaking vacuum between two measurements.

Residual vacuum under the bell is measured with a MKS Baratron™ model 690 Capacitance Vacuum Gauge.

A double stage vacuum pumping system is used to generate test pressure below atmospheric pressure and a source of nitrogen is required for applying test pressure above atmospheric pressure. The test pressure is controlled by an automatic pressure controller whose operation is commanded by the position of the APX50 piston so that it is maintained in float position.

A specific MS Windows-based command software package provides full control upon all the functions and features of the APX50.

6. Metrological Evaluation

6.1. Evaluation Method

The metrological evaluation and characterization of the APX50 was lead by the BNM-LNE French National Laboratory.

It is first important to state again that the APX50 measuring post was designed to accept existing piston cylinder assemblies with long metrological history and very well known metrological performance. Those PCA could then be used as a reliable standard for the qualification of the APX50 pressure balance.

The first experiments were carried out in the initial prototype stage in order to validate the functioning of the measuring post under vacuum. Validation consisted in determining the mobility and the falling rate of the piston in gauge and absolute modes and comparing the results to values obtained from historical measurements. The effects of quantities such as temperature, speed of rotation or residual pressure measured under the bell-jar were also studied [4].

Such experiments were repeated from early 1997 after the APX50 automatic pressure balance was delivered, in order to characterize its functioning in gauge and absolute modes.

Then, these experiments were complemented through crossfloatations of 10 and 20 cm² piston cylinder assemblies between the APX50 and another pressure balance both in gauge and absolute pressure modes in order to study the effect of the APX50 base on the determination of piston cylinder assembly effective area.

6.2. Behaviour under Vacuum

The good behaviour of the APX50 under vacuum was evaluated first by fall rate measurements of

pistons, then by the analysis of the stability of pressure over time.

In [fig. 9] there are plotted the experimental values for the falling rate of a 20 cm² PCA.

The measurements were performed in both gauge and absolute pressure modes using nitrogen and show a good agreement in the range 50 to 150 kPa. This indicates that the behaviour of the pressure balance is similar whatever the mode.

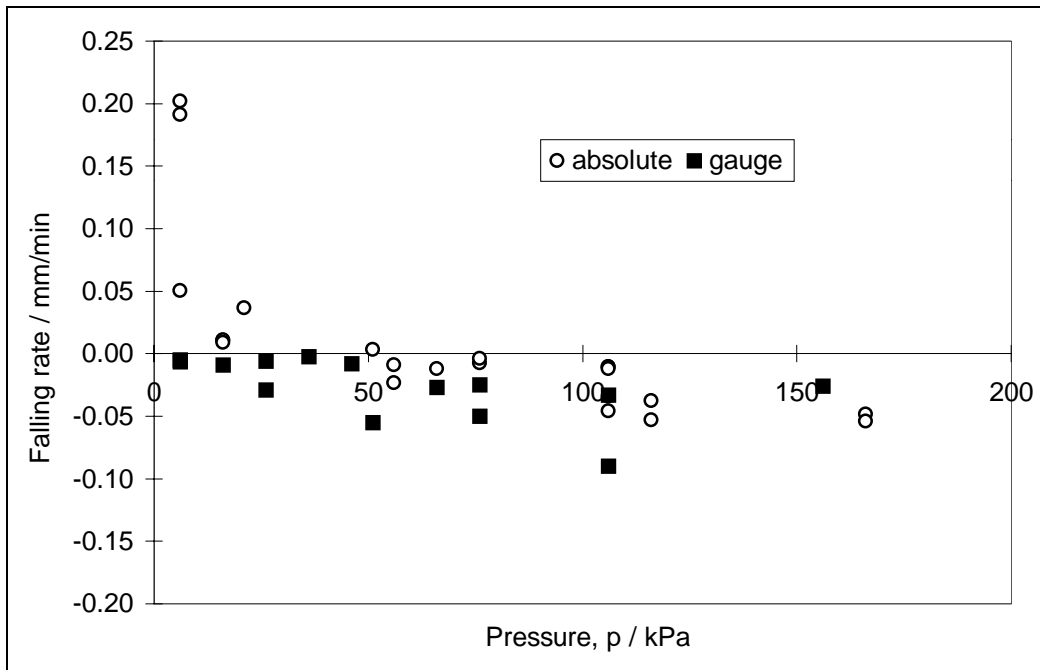


Fig. 9 : Falling rate measured for a 20 cm² assembly with nitrogen

[Fig. 10] shows the analysis of the stability of an absolute pressure of 100 kPa over 10 minutes using a 10 cm² and a 20 cm² PCA. Pressure was recorded using an oscillating quartz crystal sensor. The

pressure generated by the balance is stable within ± 0.1 Pa whatever the used assembly, this value including the repeatability of the quartz monitor.

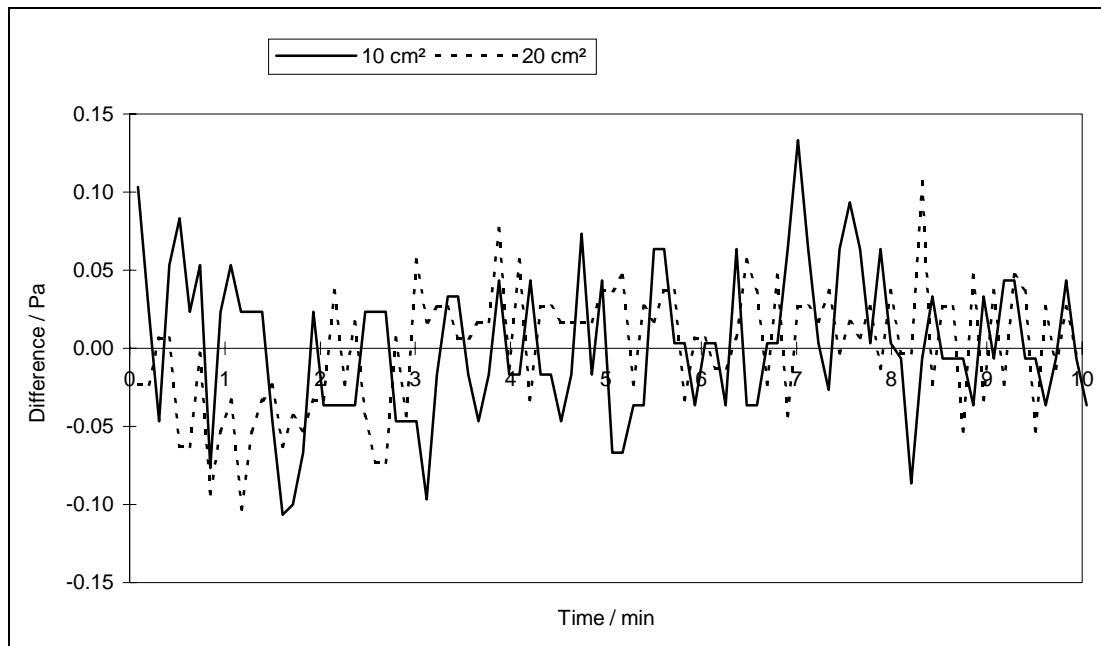


Fig. 10: Differences from the mean absolute pressure (100 kPa) measured by a quartz manometer

6.3. Behaviour of the Measuring Post

The design quality of the measuring post, including the innovative cylinder rotating system, was evaluated by comparing the determination of the effective area of a 10 cm² PCA when the PCA is mounted in the APX50 and when it is mounted in another pressure balance. Furthermore, crossfloatation results were compared to results obtained during a bilateral comparison between BNM-LNE French National Laboratory and PTB German National Laboratory.

The study has consisted of determining the effective area of the assembly mounted into the two different bases in the range of gauge pressures 20 and 1000 kPa. A direct crossfloat method with the national standard (equilibrium reached by applying small masses) has been used. The relative difference between the two calculated effective areas is $2 \cdot 10^{-6}$ which is consistent with the relative expanded uncertainty of $6 \cdot 10^{-6}$. The experimental standard deviation was calculated ($0.15 \text{ Pa} + 5 \cdot 10^{-7} \cdot p$) over the whole pressure range.

6.4. Metrological Performance of the APX50

BNM-LNE has estimated that the combined standard uncertainty achievable by the APX50 pressure balance is $\pm(0.15 \text{ Pa} + 3 \text{ ppm of pressure})$ for absolute pressures from 10 to 1000 kPa (piston-cylinder assemblies of 10 cm² effective area). Indeed, the crossfloat experiments have shown equivalent results whatever the mode of functioning, as regards the determination of the effective area and standard deviations.

7. Conclusion

Issued from a long and fruitful co-operation between DESGRANGES & HUOT and BNM-LNE French National Laboratory, the APX50 automatic absolute pressure balance represents an important step forward in the field of pressure metrology in absolute mode.

By overcoming the limitations of traditional manual absolute piston gauges and with the introduction of innovative technical solutions, the APX50 shows that the pressure balance technology is now a reliable alternative to mercury manometers.

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