AUTOMATED MASS HANDLING FOR HIGH PERFORMANCE PRESSURE BALANCES

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ABSTRACT

The pressure balance is very widely used in pressure metrology. The instrument's operating principle requires that different mass combinations be loaded on a piston to set different pressures. An automated mass handling system for an existing line of high performance pressure balances has been introduced. The new system is a simple accessory that automates mass handling in both gauge and absolute measurement modes with mass sets up to 100 kg. When combined with existing automated pressure control, automated mass handling makes fully automated operation of pressure balances possible. Automation of mass handling and pressure balance operation brings both practical and metrological benefits to pressure metrology.

1. INTRODUCTION

Pressure balances are valued in pressure metrology. However, their use is generally tedious and labor intensive. In particular, the requirement to load a different combination of masses on the piston for each pressure to be set has both practical and metrological consequences.

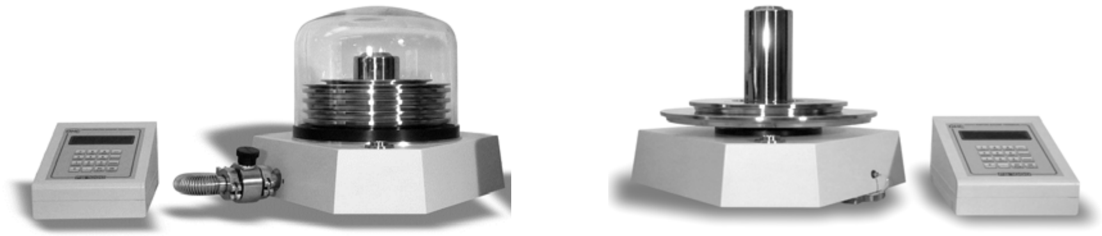
An automated mass handling accessory has been introduced for an existing line of pressure balances[1]. The accessory can eliminate the need for manual mass handling in day to day operation and, combined with automated pressure control, allows fully automated pressure balance operation.

2. DESIGN OF THE AUTOMATED MASS HANDLING SYSTEM

From the start, a main objective of the new mass handling system was to make automated mass handling a routine feature of high performance pressure balances, rather than an exclusive system for limited, special applications. The following objectives defined the project:

- To meet practicality and cost objectvices, the automated mass handling system should be an accessory to an existing pressure balance platform using existing piston-cylinder modules.
- The piston-cylinder must remain easily accessible for range changing, cleaning, etc.
- The minimum mass load should not be significantly increased relative to a manual system.
- The mass loading resolution must be fine enough to provide an adequate number of pressure increments for ranges of 10% of the maximum range of a piston-cylinder.
- There must be no friction between masses when loading and unloading them. Friction would cause mass wear, defeating one of the main benefits of avoiding manual mass manipulation.
- To support absolute pressure operation, mass must be able to be loaded and unloaded automatically within a vacuum reference, without interfering with the vacuum integrity.
- The mass handling system must integrate smoothly into remote and local pressure balance operation, preferably without separate, add-on devices and interfaces.

The new mass handling system is designed to operate with a line of pressure balances produced by DH Instruments, Inc and designated PG7000[1]. With different models, the PG7000 line covers the complete pressure range from 10 kPa absolute gas pressure to 500 MPa oil pressure. With one model, absolute pressure can be defined relative to vacuum established in a bell jar around up to 38 kg of mass (Fig. 1). With the others, up to 100 kg of masses can be loaded



(Fig 2).

Figure 1: PG7000 pressure balances

The existing PG7000 platforms, define the physical boundaries of the mass handler and mass set. To accommodate automated mass manipulation, and to provide adequate mass loading resolution, a new mass set design, specifically for the automated mass handler, is necessary. The basic principle of operation is to lift the entire mass load off the piston, to a mass selection position. In the mass selection position, masses not to be loaded are retained by the mass handling system, then the remaining mass is lowered back onto the piston.

The first consideration in the design of the mass set is the level of mass loading resolution that is necessary. From a practical and cost standpoint, less resolution requires less individual masses, which is favorable. On the other hand, when using pressure balances, mass values are sometimes loaded with resolution of 10 mg, for example to set a particular pressure point more exactly or when performing crossfloats.

Loading mass automatically with 10 mg resolution is prohibitive from a complexity and cost standpoint. In practice, it is infrequently necessary as achieving exact, cardinal pressure points is very rarely necessary and the vast majority of the pressure balance work is not crossfloating. Another consideration is that, with very high resolution mass loading, mass loading errors can occur that are small enough to not be detected. If the mass loading resolution is significantly lower than the measurement uncertainty of the system, any error in mass loading is easily identified by a large error in the actual pressure relative to the expected pressure.

The automated mass loading resolution selected is 100 g. This provides 370 increments with the 38 kg mass set and more than 1000 with the 100 kg mass set. Even with the 38 kg mass set, more than 30 increments can be achieved when running a calibration in a range that is only 10% of the piston's full range. For cases in which it is indispensable to load mass values with higher resolution, a mass loading tray is accessible so that smaller masses to complement an automated mass load can be loaded manually.

The 100 g mass loading resolution is achieved using a mass set made up of a group of masses whose values are in binary progression and a group of main masses of nominally equal values.
The binary masses are tubes with diameters that increase with mass value (Fig. 2). The individual binary mass tubes fit inside each other with no contact between them. Each mass is loaded directly onto the piston or mass carrying bell, independently from the others. For the 38 kg mass set the binary masses are from 0.1 to 3.2 kg. For the 100 kg mass set there is also a 6.4 kg binary mass.

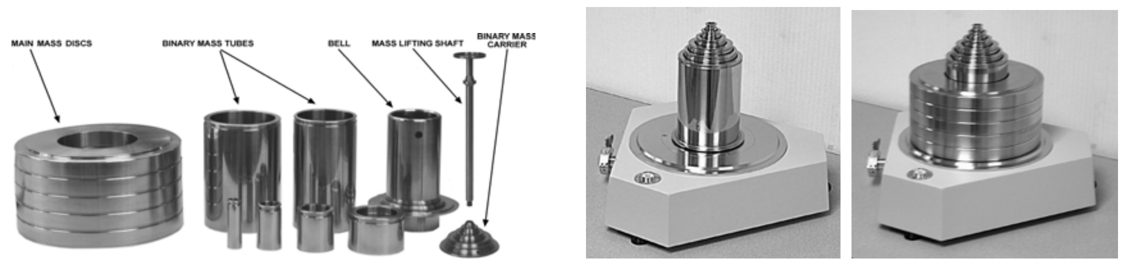


Figure 2: Complete mass set and platform with binary mass tubes (left) and main masses (right) loaded

The main masses are discs (Fig 2) which are stacked sequentially onto a ledge at the bottom of the mass carrying bell. For the 38 kg mass set there are five main masses of 6.4 kg nominal value. For the 100 kg mass set there are nine main masses of 10 kg nominal value.

To load a specified mass value, the necessary number of main masses is loaded along with the selection of binary masses needed to reach the required load as closely as possible within the 100 g value of the smallest binary mass.

The minimum mass load is the piston assembly plus the mass carrying bell. The 38 kg mass set's bell is 500 g compared to 300 g for the manual bell. The mass carrying bell for the 100 kg mass set is 800 g in both cases. So, the only change to the minimum mass load when using automated mass handling is the 200 g increase of the 38 kg mass set bell.

Installing the automated mass handling system starts by loading all the masses manually onto the piston (Fig 3). Once the masses are all loaded, the automated mass handling system is placed onto the platform over the masses (Fig 3). Finally, the mass lifting shaft (part of the mass load) is installed. To remove the mass handler and masses, the procedure is reversed.

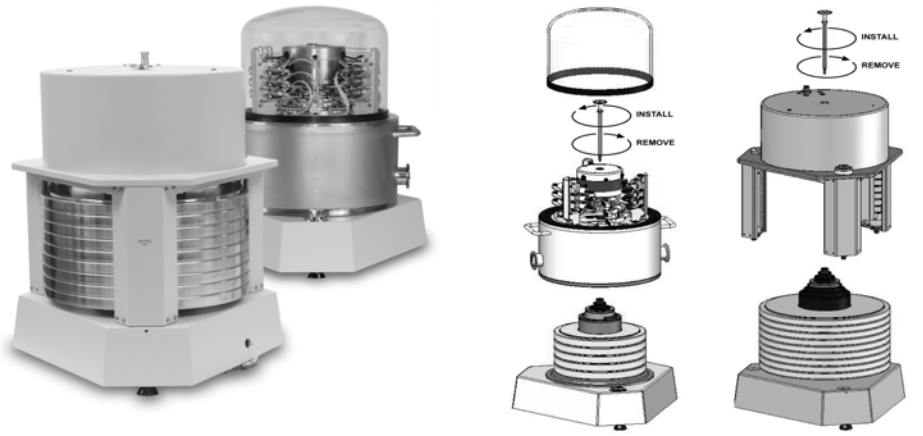


Figure 3: Installing and removing the automated mass handlers

The automated mass handling system is made up of four main sub-systems. The four sub-systems are the mass lifting and lowering mechanism, the binary mass selection system, the main mass selection system and electronic measurement and control system (Fig. 4). The 38 and 100 kg versions use the same subsystems but the 100 kg version has longer main mass selection columns, an extra binary mass (6.4 kg) and no vacuum chamber.

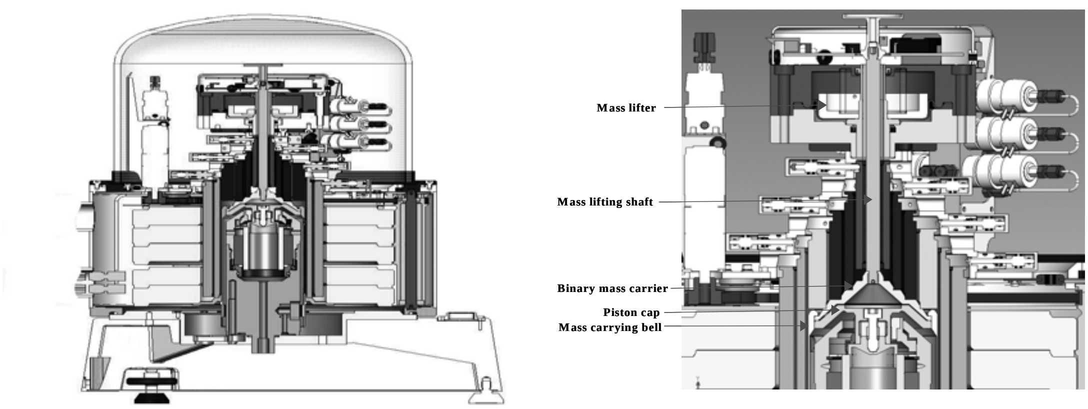


Figure 4: Cross section of automated mass handling system with vacuum reference on platform and detail of mass lifter and binary masses

Mass lifting and lowering mechanism (Fig 4): The mass lifting and lowering mechanism is used to move the mass load off of the piston to the mass selection position and back down onto the piston. It is pneumatically actuated. As the mass lifting assembly rises, it engages a ledge on the mass lifting shaft pushing it up and lifting the binary mass carrier, the mass carrying bell and all the loaded masses. Eventually, the moving mass load meets the masses that were retained by the mass handler. At the top of the lifting stroke, all the masses are and lifted. This is the mass selection position in which the binary and main mass loading systems are operated to retain masses not to be loaded. Once the selection is complete, the load, including the non-retained masses, is lowered back down onto the piston.

Binary mass selection system (Fig. 4): The binary mass selection system selects which binary masses are included in the mass loaded onto the piston. Three pins for each mass are evenly distributed around the outside, top circumference of each binary mass tube. When the mass load is lifted to the mass selection position, the pins align with a notch around the upper, outside circumference of each binary mass and can be engaged and disengaged without touching the mass. The pins are pneumatically actuated When selecting binary masses, the pins are extended to hold masses that are to be retained and retracted to allow masses that are to be loaded to be included in the mass load that is lowered onto the piston.

Main mass selection system (see Fig. 4): The main mass selection system is selects how many main masses are included in the mass loaded onto the piston. The main mass selection columns retain the main mass discs that are not to be loaded. Each column has a number of sides equal to the maximum number of main masses plus one. One side, which retains all the masses so that none are loaded, has a ledge for each mass. Each subsequent side has one less ledge. The last side has no ledges and loads all the main masses. When the mass load is in the mass selection position, the ledges on the column are across from the gaps between the main masses and the columns can be rotated without making contact with the masses. The columns are rotated synchronously by a DC motor and a drive belt. The motor is operated to rotate the columns to retain the desired number of masses, starting with the top mass and moving down. When the mass load is lowered, the masses to be retained are stopped by ledges on the column and the masses to be loaded are free to descend onto the piston.

Electronic measurement and control system: The electronic measurement and control system measures status conditions of the automated mass handler and controls its operation. The system accepts and executes commands to load specific masses and other macro commands. Measurements include an optical detector of the position of the mass load indexing switches on the main mass selection columns.

The control systems include electrical actuation of the drive air solenoid valves used to operate the mass lifting and lowering mechanism and the binary mass selection pins.

Automated mass handling when using a pressure balance to define absolute pressure relative to a vacuum reference presents some additional design challenges. For mass load changing to occur without having to break the reference vacuum, the complete mass handling system must be built-in to a vessel within which a vacuum can be established and maintained. All the components within the vessel must be able to operate without being surrounded by air.

To avoid overheating of electrical and electrically powered components, the components used were selected and tested for operation in a vacuum.

To minimize opportunities for air drive leaks to affect vacuum integrity, drive pressure is used only momentarily to complete an operation, it is never applied permanently. When operating in absolute mode, a utility vacuum supply is connected to the drive air vent port. The vacuum removes the air from drive air circuits when they are not pressurized so the differential pressure with the inside of the vacuum chamber is insignificant.

In practice, the level of vacuum obtained when using the automated mass handler in absolute mode is not measurably different from operation with the one piece Pyrex® bell jar used in manual mode. Typical vacuum obtained with a conventional rotary vein pump is on the order of 2.5 Pa (20 mTorr). However, since the vacuum does not need to be broken and reestablished for each mass increment, it becomes practical to use a turbo-molecular vacuum pump. Two KF40 vacuum connections are provided on the vacuum chamber to support setting and measuring a lower reference vacuum. Using a turbo pump, reference vacuum is typically less than 0.5 Pa (4 mTorr).

3. BENEFITS OF AUTOMATING MASS HANDLING IN PISTON GAUGES

DHI has been using automated mass handling on PG7000 pressure balances in its pressure metrology laboratories since the spring of 2003. This direct experience reveals that automating mass handling brings both practical and metrological benefits.

Practical benefits include:

- Improved operator working conditions by eliminating the chore of manually loading and unloading masses reduces the physical labor associated with pressure balances operation.
- Fewer operator errors by more consistent procedure and elimination of mass loading errors.
- The time required to complete pressure increments is reduced, especially in absolute mode.
- More efficient use of equipment as fully automated equipment can be operated at nigh and over weekends when no operator is present.

Metrological benefits of automating mass handling include:

- Improved stability of mass over time – Greatly reduced handling of the masses and of wear due to sliding masses on and off of the mass carrier reduces changes in mass values over time[2].
- More consistent leveling of the piston – The weight distribution on the pressure balance platform and the bench upon which it rests remains constant rather than changing as mass is added and removed to change pressures.
- Greater availability of data – Automated operation makes it practical to perform more complete tests such as repetitive runs to evaluate repeatability or increasing the number of calibration points when characterizing transfer standards.
- In absolute mode with vacuum reference:
- not having to make and break the vacuum at each pressure point results in more consistent reference vacuum values from measurement to measurement.
- operating at lower levels of reference vacuum reduces the absolute uncertainty in reference vacuum measurement[2].

In our experience, one area in which the benefit of automated mass handling and automated pressure balance operation has been the most noticeable is for the original characterization and maintenance over time of pressure transfer standards. DHI produces transfer standards in ranges from atmospheric pressure to 200 MPa. With the most current technology introduced in the summer of 2003, these provide measurement uncertainty specifications of ± 0.008% of reading. Achieving these specifications in the original product and maintaining them over time requires the use of pressure balances in the characterization process and for their accredited calibration and recalibration. Without automation of the pressure balances used it would not be feasible to offer these products. The labor required to characterize the transducers manually would be prohibitive. Consistently achieving the necessary level of performance from the pressure balances, on a day to day basis, in a production laboratory environment would also be nearly insurmountable. This is particularly true in the ranges requiring operation of the pressure balance in absolute mode with a vacuum reference.

With automated mass handling, the pressure balance operation can be fully automated and operated uninterrupted when operators are not present. The influences of making and breaking the vacuum and of inconsistency in operator procedure are eliminated. Figure 10 shows the results of a characterization run of five 2 MPa absolute transducers before the transducers have been compensated. Each run includes two full scale pressure sequences with 28 pressure points in each sequence. The plot shows the deviation of transducers relative to the pressure balance. The two sequences repeat so well for each transducer that it is barely possible to distinguish them. For each individual transducer, hysteresis and localized non-linearity at the level of a few ppm are very well defined. The test is completed in less than three hours including 1.5 minutes of dwell and data acquisition at each point. Manually, the test required a full day with a dedicated operator and the results were of lower quality with frequent aberrant points.

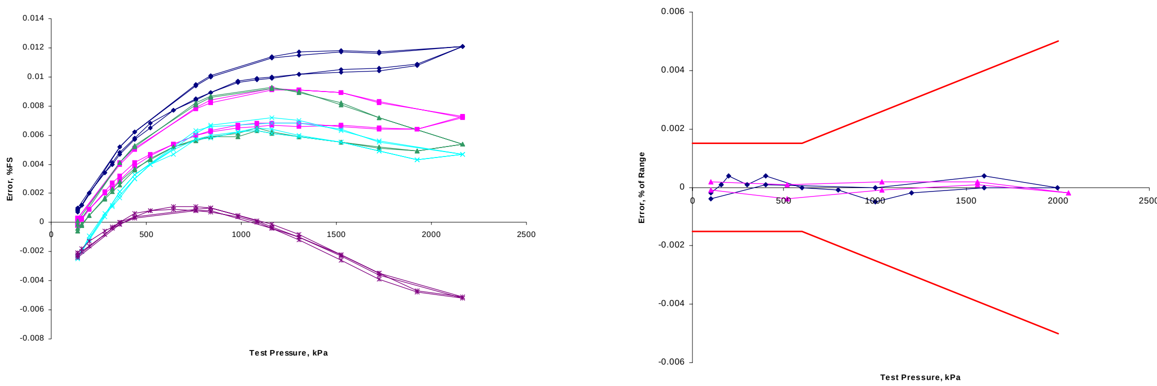


Figure 5: Deviations of five 2 MPa absolute pressure transducers from automated pressure balance reference before (left) and after (right) characterization

3. CONCLUSIONS

The practical benefits of automating the handling of masses for pressure balance are evident. There are also less obvious metrological benefits such as more consistent procedures and more consistent vacuum reference in absolute mode. The introduction of automated mass handling systems that are accessories to standard pressure balance platforms in a reasonable, bench top footprint and at cost that increases the price of a system by well under 50%, makes automated mass handling and fully automated pressure balance operation much more accessible than they have previously been. This is likely to make automated mass handling a common feature of high performance pressure balances, removing the manually intensive procedures for which pressure balance are known. It also makes it possible to enjoy the unequalled precision and measurement uncertainty of the pressure balance in applications for which its use manually could not be justified.

REFERENCES

[1] DH Instruments, Inc., PG7000 Reference Level Piston Gauges, DH Instruments Product Brochure 9960.1.B.10, 1999.

[2] Bair, M. and Delajoud, P., “Uncertainty Analysis for Pressure Defined by a PG7601, PG7102, PG7202 or PG7302 Piston Gauge”, DH Instruments, Inc. Technical Note 7920TN01C, 2003.