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Pressure Balances for Industrial Applications up to 120 MPa

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Abstract

The design and development of a series of pressure balances, operating in liquid media up to 120 MPa and in gas media up to 12 MPa, have been started during a recent collaboration between the Italian company SCANDURA & FEM and the I.N.RI.M (Italian National Research Institute of Metrology) in Italy. The details of the project design for the pressure balance in liquid media up to 120 MPa are presented here . The chosen strategy has been decided in such a way to produce a compact pressure balance easy to move, but at the same time equipped with all the measuring sensors needed to compensate the errors due to the main influence quantities. The main metrological characteristics of some piston-cylinder units were experimentally carried out and some interesting results are presented here .

1. Introduction

The goal of this design was to produce a series of pressure balances with appreciable metrological characteristics and suitable as well for an industrial use.

To fulfill these requirements, a compact balance, easy to carry, with a limited total weight and at the same time accurate and efficient, has been developed.

2. Design of the Pressure Balance

For the 120 MPa full scale pressure balance, a tungsten carbide piston-cylinder was used. The cylinder has been inserted in a stainless steel body that contains the piston-cylinder assembly on its top side in such a way to keep low the center of gravity of the masses used to balance the force due to the pressure applied to the effective area of the piston-cylinder unit. In this stainless steel body two mechanical holes have been planned, one for a temperature probe for measuring the piston-cylinder temperature, the other one is used to purge the measuring fluid.

As the piston-cylinder assembly is of the "free deformation" type, the pressure tight is guaranteed from a rubber O- ring positioned at the bottom surface of the cylinder. The top side of the piston has been integrated in another stainless steel part that sustains the disc carrying the masses. After the insertion of the bottom side of the piston into the cylinder, this part is screwed to the body containing the same cylinder. In this way, a mechanical assembly, with the following main tasks will be achieved:

- to allow the piston to flow across the cylinder defining at the same time the full piston stroke,
- to define the points of the application force on the assembly,
- to guarantee the assembly verticality,
- to sustain the disk carrying the masses,

- to purge the fluid that slowly flow through the piston-cylinder gap, and
- to use the probe for the temperature measurement of the piston-cylinder unit.

A stainless steel weight carrier is put on the mechanical component containing the piston and its surface wraps up this component without any mechanical interference with the same. A small extension, at the bottom part of the weight carrier , sustains the masses inserted from the top and lying on each others in order to achieve the desired total mass.

The stainless steel masses are of different sizes and shapes in order to realize all the pressures between the minimum and the full scale with a resolution according to the smallest mass in use. In the central part of each mass a cavity, closed by a lid, has been realized, in which different stainless steel spheres, with different diameters, can be inserted to adjust the mass value to the nominal one. These adjustments are needed to compensate the errors due to the machinery tolerances of all the components that are involved in the measurement process. This procedure will allow to declare for each mass the nominal value in pressure units that it counterbalances when used on the weight carrier under specified reference conditions . In Fig. 1 the mechanical assembly of the 120 MPa pressure balance is given.

Different pressure balances models are considered; from the simplest one, totally mechanical, to the complete one, with the motor to drive the piston rotation and with all the sensors needed to measure and to compensate the errors due to the main influence variables. In this case a microprocessor based electrical board collects the data from the different sensors and, combining these data with the constants of the system, gives the pressure value according to the pre-defined mathematical model. The total mass value is calculated from mass value of individual weights, indicated in the certificates and reported into the memory of the electrical board. A barcode identifies each mass and can be read at the time of mass use.

The integrated sensors are: a barometer for the atmospheric pressure measurement, an ambient temperature probe, a relative humidity sensor, a thermo-resistance for the measurement of the piston-cylinder temperature and a proximity sensor to collect information about the floating level of the piston.

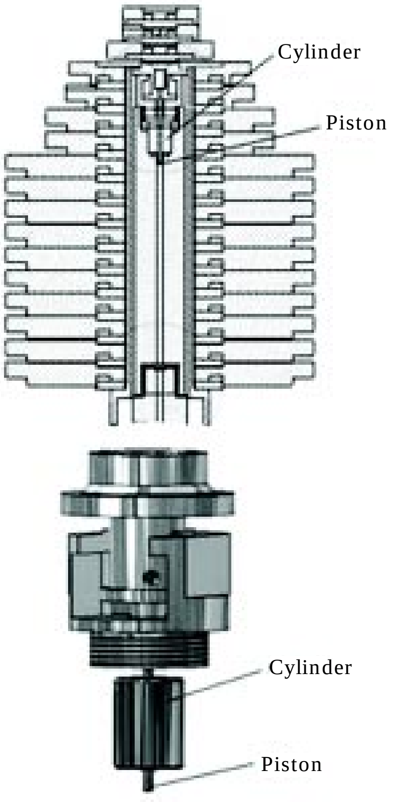

Fig. 1. Pressure balance, 120 MPa and Measuring assembly

3. Metrological Characteristics

Three piston-cylinder assemblies have been initially produced: SCAND1, SCAND2 and SCAND3. For each assembly the following tests have been performed for a preliminary evaluation:

- piston fall rate as a function of pressure,
- rotation speed of the piston and mass assembly as a function of time,
- effective area of the assembly as a function of pressure, and
- sensitivity of the cross-floating of two pressure balances.

All the tests related to piston fall rate and assembly rotation speeds have been performed with the balance isolated on its own.

All the data collected from a proximity capacitive sensor have been managed by a LabView software program prepared at INRIM. After the pressurization of the circuit and after five minutes of stabilization time, the tests have been started. For each pressure value, the fall rate speed has been carried out at least seven time. During these tests the temperature of the assemblies has been measured because the piston fall rate can be significantly influenced by temperature. In Fig. 2, the values of the mean piston fall rates versus pressure are reported for the piston-cylinder assemblies, SCAND2 and SCAND3. For all three assemblies, the behavior of the piston's fall rate is linear as a function of pressure and so an eventual extrapolation from 100 to 120 MPa would be certainly reliable.

In one case (SCAND1), the fall rate values (120 μs^{-1} at 100 MPa) are higher then the others; this depends on the radial piston-cylinder gap that is bigger than the project target. SCAND1 unit has a too high fall rate. Equilibrium will be kept only for 1 minute making this unit non practical to be used. The other units fulfill the project target requirements.

In Fig. 3, the variation in piston-cylinder gap along the piston-cylinder engagement length is reported, as it has been carried out from a series of dimensional measurements done at the INRIM laboratories. As indicated in Fig. 3, the radial clearance is very high; this is caused by large cylinder irregularities (parabolic behavior) while the piston is extremely regular. For this reason, the cylinder orthogonality in respect of the axis of rotation has to be realized and checked in order to give reproducible values of the effective area and piston fall rates.

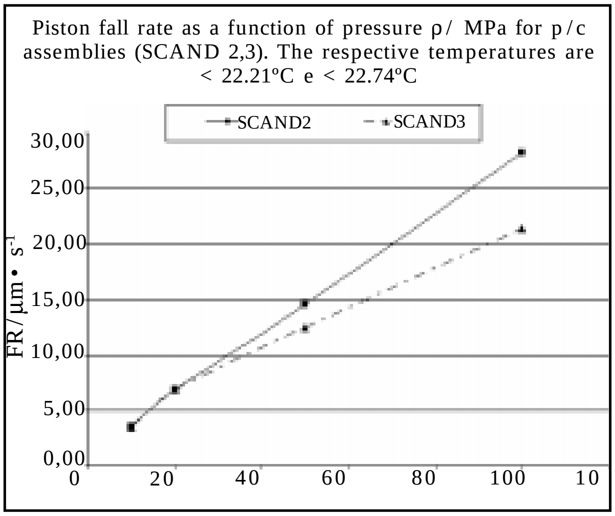

Fig. 2. Piston fall rate vs p

The standard deviations of the fall rate measurements of the piston, for each pressure point and for each assemblies, are different because the low fall rates (SCAND2 and SCAND3) inevitably bring to highest standard deviations. This is mostly evident at 10 and 20 MPa.

For all the three piston-cylinder assemblies the behavior of the reduction of the rotation speed is extremely regular as a function of time. After 30 minutes the reductions of the rotation speed starting from 37.5 rpm is 25.0 rpm for SCAND1, starting from 30.0 rpm is now 5.2 rpm for SCAND2 and starting from 33.3 rpm is now 2.0 rpm for SCAND3.

As the rotation speed reduction is regular, this qualitatively represents a proof of the regularity of the pressure distribution in the gap of the pistons and cylinders SCAND1, SCAND2 and SCAND3 and the fact that there are no large mechanical friction between piston and cylinder.

The effective areas of the three piston-cylinder assemblies have been determined from pressure cross-floating with one of the INRIM pressure national standard and taking into account each influence quantity during the cross-floating.

The mean values of the affective areas of SCAND1, 2 and 3 at the atmospheric pressure and at the reference temperature of 20 °C, are respectively equal to 4.08940 mm^2, 4.08576 mm^2 and 4.08507 mm^2. These values fit with the values derived from dimensional measurements [1].

The respective values of the pressure distortion coefficients λ are 1.32 x 10^{-6} MPa^{-1}, 1.51 x 10^{-6} MPa^{-1}

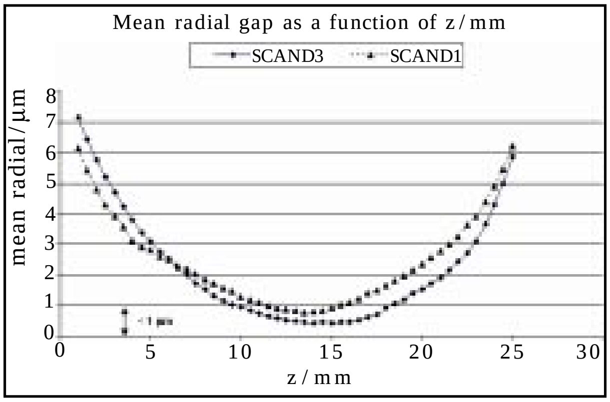

Fig. 3. Piston-Cylinder radial gap

and 2.03 x 10^{-6} MPa^{-1} and they have to be confirmed by a more accurate experimental analysis and by using the finite element calculation method (FEM) as previously done for other pressure balances [2-3].

The sensitivity tests have been performed comparing the pressures measured by the national standard pressure balance and by the piston-cylinder assemblies SCAND 1, 2 and 3. For each of the assemblies, the sensitivity values range from 1.2 x10^{-6} to 2.5 x 10^{-6} over the full measuring pressure range.

4. Conclusions

The following conclusion are drawn from the present study.

- The piston-cylinder units here presented have an acceptable geometrical quality (the average radial clearance span from 6 μm to 0.5 μm). Of course this value is larger than in the top metrology piston-cylinder units where radial clearances are generally < 1 μm; but the piston-cylinder considered here are for industrial use purposes;
- The piston fall rate, measured at the pressure of 100 MPa, using as the pressurized medium, the di-ethyl-hexyl sebacate, changes according to the mechanical quality of the piston-cylinder from 20 μm s^{-1} to 120 μm s^{-1}. Acceptable target for pressure balances of industrial use will be piston fall rate below 40 μm s^{-1} at the 120 MPa pressure;
- The quality of the piston-cylinder assemblies is confirmed by the regular behaviors of the rotation speed versus time; starting at approximately 30 revolutions per minutes (rpm), after 30 minutes, the rotation speeds of the assemblies are from 25 rpm to 5 rpm according to their mechanical quality;
- The behaviors of the effective area (nominal value is 4 mm^2) as a function of pressure which is strictly linear as expected for a free deformation piston-cylinder unit;
- The pressure sensitivity was found between 1 x 10^{-6} and 2.4 x 10^{-6} at 100 MPa.

The relative expanded uncertainty (k=2) of pressure measurements, in all the measurement range of the pressure balance, is always between 50 x 10^{-6} and 100 x 10^{-6}) of the applied pressure. Even if the proposed pressure balances are for industrial applications, they are oriented to an easy use with motor drive system not affecting the pressure measurements and capabilities of data acquisition for real time pressure values calculations.

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