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MEASURING THE DENSITY OF GASES WITH THE AID OF FREE MAGNETIC SUSPENSION

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ABSTRACT

Two types of balances for the measurement of gas densities are described. The first is derived from the well known gas density balance by the application of automatic compensation. The second uses free magnetic suspension of a hollow glass sphere,where the exciting current of the magnetic system serves as the signal for the buoyancy.

Measurement of the density of gases is important in chemical production. It can also contribute to the analysis of mixtures, as it is obvious for binary ones. If combined with the determination of other physical properties, it may be useful for the analysis of ternary mixtures /1/.

One of the most simple and accurate measuring methods for the density of fluids is based on the buoyancy of a solid body.

$$A = \rho g V,$$

where ρ is the density to be determined, g the acceleration of fall, V the volume of the body.

Starting from the principle of automatic compensation, which is to day a common feature of all vacuum balances, we have built in our laboratory a density balance for gases. Figure 1 is a schematic drawing of the instrument.

The balance beam carries on the left side a hollow sphere of glass, while to the right end, two discs of glass are fused. These discs support two flat coils, which at present are wound of copper wire and cemented to the outward directed surfaces of the discs. In an advanced stage of development, they will be produced by photoetching.

A pair of horse shoe-magnets generates a magnetic field, which penetrates the upper and lower parts of the coils. If a current flows through the coils via the taut bands by which the beam is suspended, it generates a Lorentz force, which can be used to compensate the buoyancy of the sphere. In equilibrium, the current

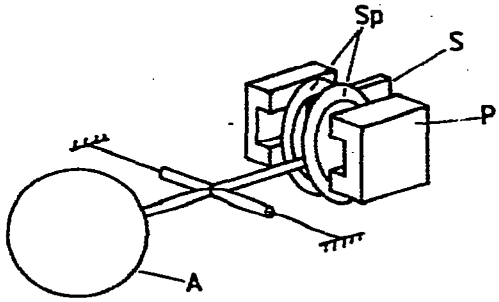

Fig.1 Schematic drawing of the gas density balance

A hollow sphere P permanent magnets
Sp discs with flat coils S capacitive sensor

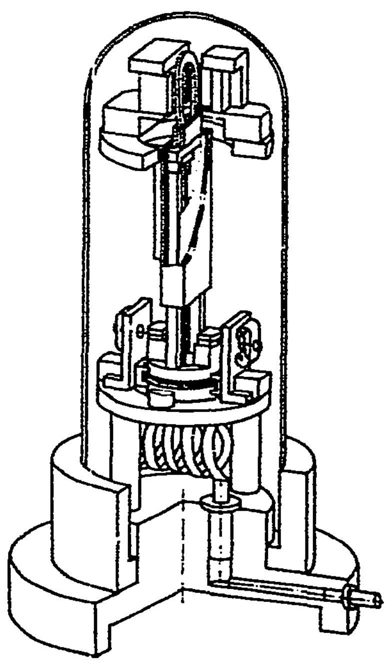

Fig.2 Sectional drawing of the self compensating Bodenstein manometer

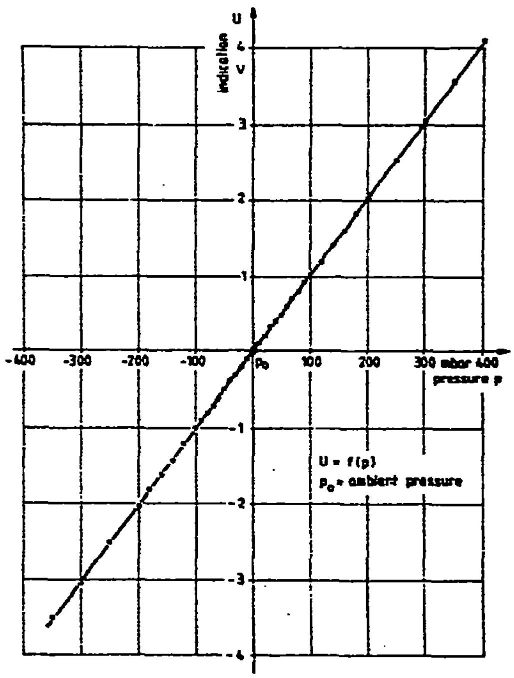

Fig.3 Calibration curve of the Bodenstein manometer

is proportional to the density of the gas if the system has been equilibrated in vacuum.

The position of the balance beam is observed by a capacitive detector, which is formed by one evaporated metal electrode at each adjacent surface of the glass plates and three solid electrodes attached to the casing of the balance and arranged centrally between the glass plates. If the balance beam is deflected, the electrodes on the glass plates are displaced and the mutual capacitances between the outer electrodes and the central electrode of the stationary system are changed in opposite sense. With the aid of a carrier frequency system, the displacement is converted into a voltage, which controls the compensating current.

It should be mentioned, that the whole movable system has to be covered with evaporated glass, to ensure the internal mass compensation of sorption layers, which is possible, if the surface area of the glass plates equals that of the sphere.

The system has so far shown an accuracy of better than 10^{-3} of full range under test with air, nitrogen and hydrogen.

In order to make automatic corrections with regard to pressure, an automatically Bodenstein-Manometer /2/ has been developed, which is shown in the schematical diagram fig. 2.

A hollow helix of fused quartz is deflected by a differential pressure. By the deflection, a quartz fiber is bent, which, for its part, exerts a force on a lever. This force is compensated by a flat coil between the poles of two horse shoe-magnets. The position of the lever is observed by a capacitive detector of the kind used in the density balance. In equilibrium, the current through the moving coil is proportional to the pressure difference. The influence of the modulus of elasticity is eliminated. A calibration curve of the manometer is shown in fig. 3.

In an earlier paper /3/ the use of free magnetic suspension for density measurement has been suggested. For this purpose, the lower magnet in the schematic drawing of fig. 4 is enclosed in a glass enveloppe, while the upper one is suspended from the beam of an electronic analytical balance.

In order to attain a better stability of the suspended body, which is a hollow sphere of glass with a diameter of 5 cm, it is provided with two flat cylinders of cobalt iron alloy. These cylinders are attracted by two magnetic systems fixed to the casing, as it is shown in fig. 5. It can be seen from the slide, that the magnetic systems are composed of soft iron cylinders, provided with control windings and enclosed by a cylindric shell and that two permanent magnets are inserted between the distant ends of the iron cylinders and the flat bottoms of the casings. Thus, a permanent magnetic field is generated in each gap near the sphere. The permanent magnets are proportioned in such a way,

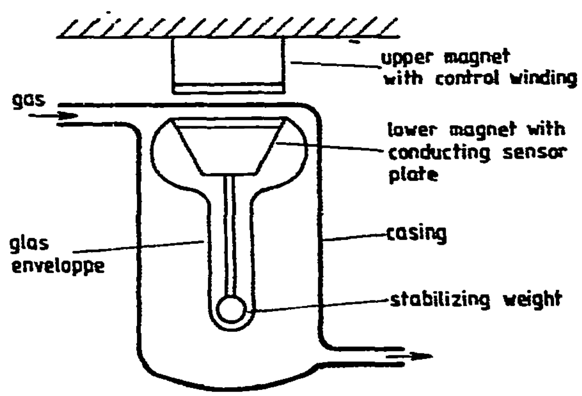

Fig. 4 Gas density measurement with the aid of magnetic suspension

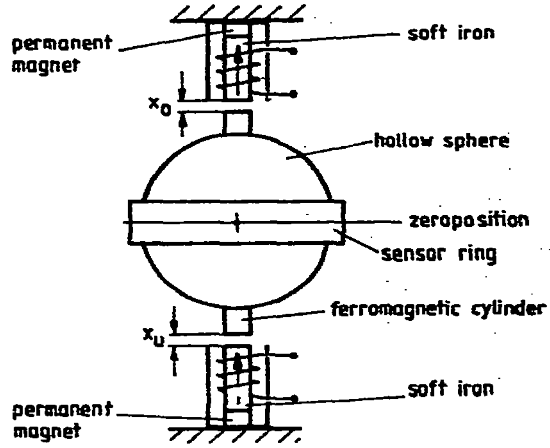

Fig. 5 Magnetic suspension of the sphere

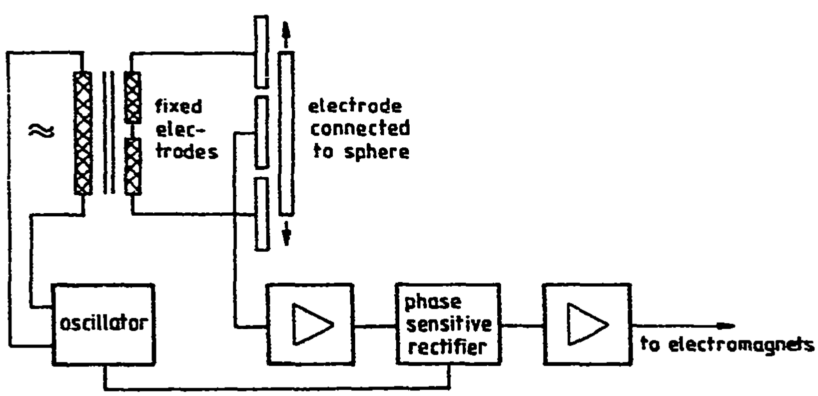

Fig. 6 Blockdiagram of the position control

that the sphere can be supported in a central position between the pole pieces with rather strong radial restoring forces.

The necessary axial restoring forces are generated by a control circuit, comprising a capacitive sensor, a controller and amplifier and the control windings around the magnets. Figure 6 shows the block diagramm of the position control. The sensor is derived from the flat one used in the density balance and the manometer. It consists of one metal ring attached to the sphere and three coaxial rings, rigidly held in position by insulators connected with the casing. The characteristic of the sensor is shown in fig. 7. Between the forces acting on the ferromagnetic cylinders at the sphere and the current through the control windings, a parabolic law is valid, as can be seen in the diagram of fig. 8 with distance from the upper pole as parameter. It can be seen, that in the central position, the superposition of the parabola for the respective forces results a straight line, which intersects the F-axis at the value of the weight.

If the system has been equilibrated in vacuum, the current will be proportional to the density of any gas admitted to the recipient.

At present, the useful resolution is 1 mg/l. The drag of streaming gases presents a problem. For one thing, the exchange of gas should be as fast, as the response time requires, for another thing, it should be as slow as possible, to avoid erronious forces. Careful design of the casing will permit a useful compromize between speed of response and accuracy.

As in the case of the already described density balance, the measured densities have to be reduced to standard conditions.

A microcomputer has been prepared for this task. It is fed with the value of absolute pressure, provided by the Bodenstein-Manometer and the value of temperature, contributed by a measuring circuit with a platinum resistance thermometer.

The influence of sorption layers at the surface of the hollow sphere can be eliminated, using a second magnetically suspended body of the same surface and weight as the sphere but with a considerably smaller volume. This body could f.i. consist of two slotted circular discs put together in perpendicular position and provided with pole pieces, just as the sphere. The difference of the controlling current of the two systems would be independend of the amount of adsorbed gases or vapours.

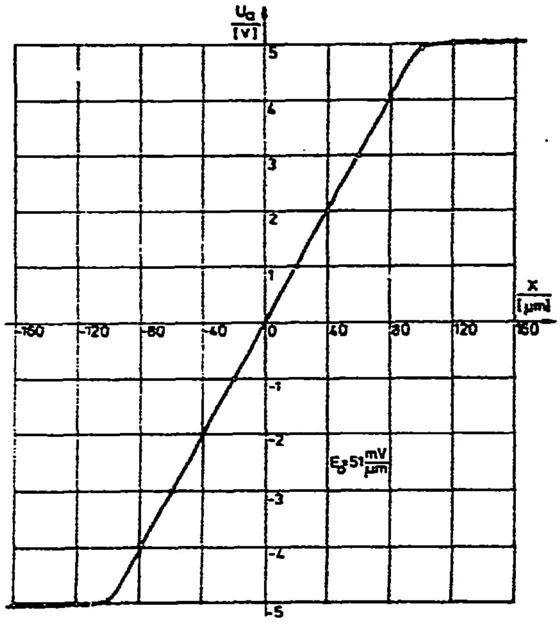

Fig. 7 Characteristic of the sensor

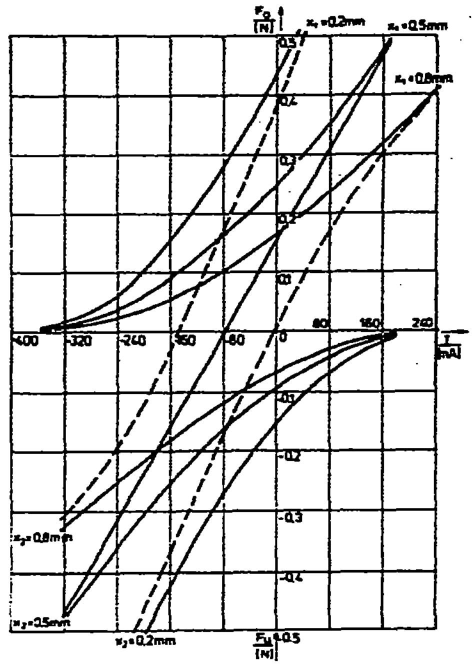

Fig. 8 Static characteristic of the magnetic suspension

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