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Developments in the Accurate Measurement of High Pressures

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With 7 Figures in the Text

Abstract

The measurement of steady high pressures in a fluid system with the highest accuracy demands the use of pressure balances (free piston gauges) of accurately known effective areas. This requires a precise knowledge of the way in which the effective areas of the piston-cylinder assemblies concerned vary due to the elastic distortion caused by the applied pressure.

Two methods which have been directed to the solution of this problem are described. The first depends on a principle of similarity as applied to the deformations of two assemblies of the same general dimensions but constructed of materials having substantially different elastic moduli. The second method makes use of measurements of the flow characteristics of the pressure transmitting fluid using two pistons having a known difference of diameter.

The distortion factors are shown to be representable as linear functions of the pressure, so that the effective area at pressure P is connected with that at zero pressure by expressions of the form

$$A_P = A_o (1 + \lambda P)$$

where λ may be termed the distortion coefficient.

The final accuracy of the measured distortion coefficients is about $\pm 2\%$, which corresponds to an uncertainty in effective area of about ± 1 part in 10^5 at 1000 bars increasing in proportion to the pressure at higher pressures.

Some aspects of the practical calibration of pressure balances, carried out by direct balancing against assemblies calibrated by the methods described, are considered.

1. Introduction

The rapid development of high pressure techniques in the last few decades has given rise to considerably increased interest in the accurate measurement of high pressures, both in fundamental physics and chemistry and in the many associated industrial applications. In many thermodynamic studies, as for example the pressure-volume-temperature relations and virial coefficients of gases, the Joule-Thomson effect and the measurement of vapour pressures, the demands on accuracy are severe. Nevertheless until quite recently progress in high pressure measurement was much retarded compared with the measurement of the other thermodynamic variables, temperature and volume, and it is only within the last few years that some notable advance has been achieved. The object of this paper is to present an up-to-date account of some recent developments at the National Physical Laboratory which have contributed to these improvements. The discussion is restricted to the case of steady pressures.

There are two quite independent basic methods by which pressures may, in principle, be measured or established, with precision, or by which other pressure-measuring equipment may be calibrated. The first, usually represented in practice by the mercury manometer or some extension of it, determines a pressure in terms of the height of a column of liquid of known density under known conditions of gravity. In the second method, pressure is measured directly in terms of the force exerted on a surface of known area. In practice this reduces to the use of the pressure balance, or free piston gauge, in which the force due to the pressure-transmitting fluid acting on the base of a cylindrical piston, free to move in an accurately matched cylinder, is balanced by a known downard force derived from calibrated masses suitably supported on the piston. The calibration of the instrument is expressed by stating the "effective area" of the piston-cylinder assembly, and owing to the distortion caused by the applied forces this quantity may be expected to vary with pressure.

In the high pressure region proper, however, the pressure balance is virtually the only instrument in the field for practical pressure measurement of the highest accuracy, as high pressure variants of the mercury manometer are very difficult to operate even for fundamental calibration purposes. Two problems therefore present themselves:

(i) the establishment of the effective areas of suitable piston-cylinder assemblies in absolute terms at low pressures;

(ii) the determination of the changes of effective area at higher pressures due to the distortion of the assemblies resulting from the applied pressure.

With regard to (i) details are being dealt with in other publications and we shall only summarize the present position. In the more restricted field of barometric pressure the National Physical Laboratory has for many years maintained standards based on the mercury manometer and reaching an accuracy of a few microbars (Sears & Clark 1933; Elliott, Wilson, Mason & Bigg 1960). Recent work has shown that the effective areas of piston-cylinder assemblies based on comparison with a mercury manometer of a few atm range, and those calculated directly from diametral measurements on the components, are in agreement to within about 1 part in 10^5 (Dadson 1955, 1958).

The elastic distortion effect (ii) was for a long time considered to be a fundamental difficulty in the use of the pressure balance as an independent primary standard, but this situation has now been completely altered with the development