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MEASUREMENT OF THE RELATIVE DEFLECTION OF TWO TORSION BALANCES IN THE 10^{-9} RAD SENSITIVITY RANGE*

By

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Using a simple method, a d.c. signal sensitivity of about $0{,}3\times10^{-9}$ A/10^{-9} rad was achieved in an apparatus designed for the measurement of the relative deflection of two torsion balances. This degree of sensitivity allows the Eötvös experiment to be repeated with greater accuracy than has been attained hitherto. Signal sensitivity can be raised further by common electronic methods.

Higher accuracy repetitions [1, 2] of the famous Eötvös experiment concerning the equivalence of gravitational and inertial mass [3] and a number of recently published papers [4—7] have brought gravitational research into the foreground of modern physics. A newer repetition of the Eötvös experiment in Hungary required the registration of changes in the angle difference between two torsion balances [8]. This was achieved by comparatively simple means, using a suitable optical arrangement and a laser source. This paper presents a brief description of the method.

Known methods for measuring the deflection of a mirror have until now employed photoelectric autocollimators, which can attain sensitivities of about 10^{-7}—10^{-8} rad, but only if mirror diameters of about 40 mm are used. R. Hakner [9] proposed to use an optical path length of 15 m and a continuous 3 W laser source.

In our method two torsion balances (Fig. 1) consisting of the masses $M_1 - M_4$, respectively, were placed a distance 820 mm apart. The relative angle difference —φ — of the two mirrors T_1, T_2 attached to the two balances had to be measured with a sensitivity of 10^{-9} rad. A serious problem arose, however, because the variations of the gravitational field strength at the measuring place can make the balances deflect simultaneously as much as 10^{-5} rad.

The most suitable method of overcoming this strong "background noise" seems to be the familiar "optical-wedge" — mirror arrangement. In this arrangement the deflection angle of the incident light beam depends only on the value of φ. To determine the variation of φ (viz. the variation in the deflection $\delta = 2\varphi$ of the exit beam), a pair of silicon photodetectors D_1, D_2 was placed

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* Dedicated to Prof. L. Jánossy on his 60th birthday.

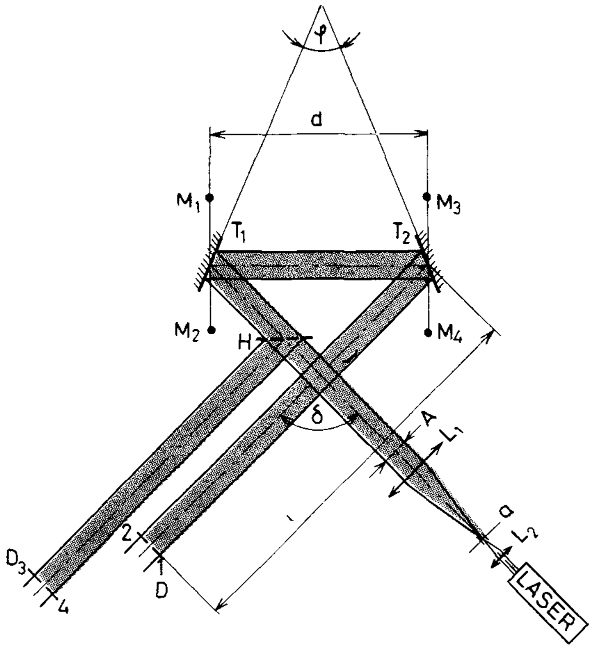

Fig. 1

at a given distance (l) into the exit beam, and the displacement of the spot on the detectors was measured by the difference signal produced.

Another problem was that the sensitivity of the balances had permitted the use of only a very thin fibre, which means that the diameter of the mirrors is limited and thus diffraction of the light beam is considerable. Taking into account all the different aspects, a mirror diameter of 20 mm and a free aperture beam of $A = 15$ mm were chosen. The measuring room permitted a light path of $l = 5000$ mm on the exit side, so that the displacement of the spot was 10^{-5} mm. The sensitivity of the silicon detector was 0.6—0.8 μA/μW, that of the recording galvanometer $0.3 \cdot 10^{-9}$ A. The required total intensity of the measuring spot was about 0.3 mW. The transmittance of the optical system, including losses by lenses, windows and a second reference beam (described below), was 0.2 and thus the intensity of the incident beam 1.5 mW.

For an objective lens (L_1) having a focal length of 840 mm, the optimal source diameter (a) is about 0.1 mm. The energy density in the pinhole aperture must therefore be 20 W/cm^2, which can be achieved only with a laser source. For this purpose a 2 mW He—Ne laser was used. The 632.8 nm wavelength light was focused into the pinhole aperture by a lens (L_2) with a focal length of 110 mm. This telescope system secured an ideal (Gaussian) light distribution for the measuring beam.

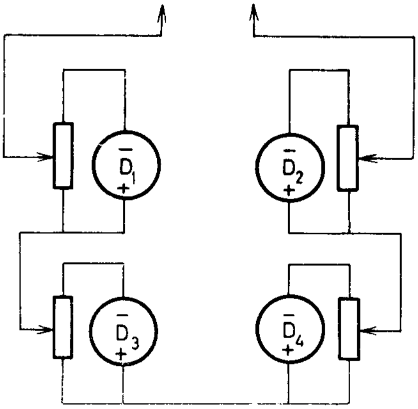

Fig. 2

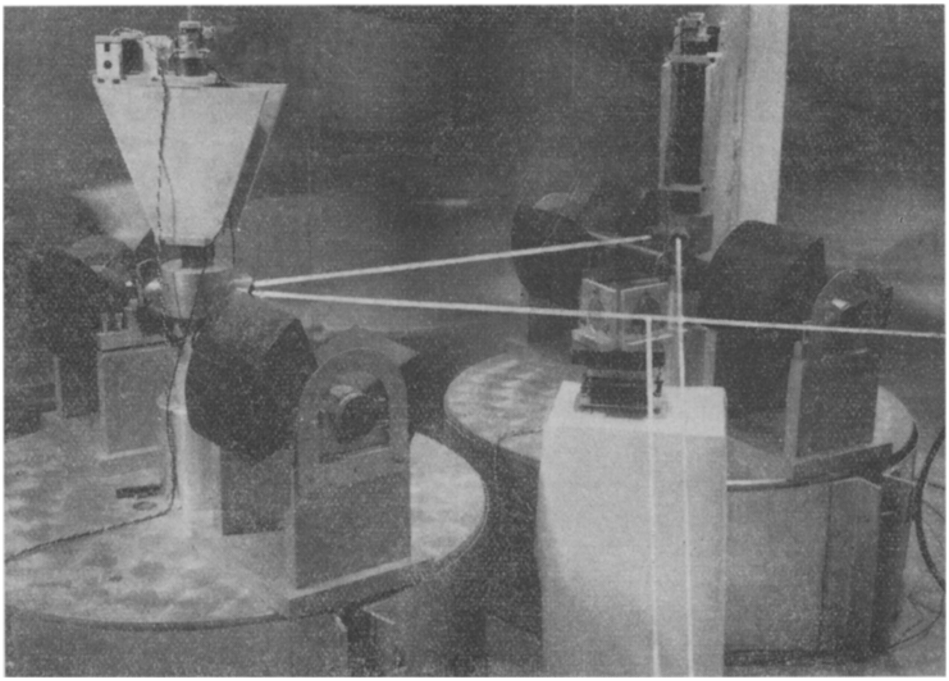

Fig. 3

The role of the reference beam coupled out of the semi-transparent mirror H was to eliminate errors arising from possible small displacements between the separate stone blocks supporting the optical elements and detectors. The reference spot fell on a second detector pair D_3, D_4 and the two detector pairs were connected in such a way (Fig. 2) that a simultaneous displacement of both the measuring and the reference spots did not affect the measuring signal.

Calibration of the total system up to 10^{-4} rad was performed with a Hilger autocollimator of 10^{-6} rad sensitivity. Deviations from linearity could be observed above 10^{-5} rad. For calibrating the high-sensitivity range a 60^0 hollow (air) prism was placed in the incident beam and the deviation inside the prism was varied by air pressure.

The whole system of optical ray paths, balances and detectors was placed under a separate shield to protect it against heat and air turbulence. Control and registration of air pressure change were carried out from another room.

The balance (without shield) and the ray path around them are shown in Fig. 3.

In the course of the calibration measurements of the apparatus a d.c. signal sensitivity of $0.3\ 10^{-9}$ A/10^{-9} rad was achieved, which agrees well with calculated values.

Acknowledgement

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ИЗМЕРЕНИЕ ОТНОСИТЕЛЬНОГО ОТКЛОНЕНИЯ ДВУХ КРУТИЛЬНЫХ БАЛАНСОВ В ДИАПАЗОНЕ ЧУВСТВИТЕЛЬНОСТИ 10^{-9} РАД

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Резюме

С помощью сравнительно несложного метода в аппарате, созданном для измерения относительного отклонения двух крутильных балансов, была получена чувствительность сигнала прямого тока в 0,3F 10^{-9} A/10^{-9}. Эта степень чувствительности позволяет повторить опыт Этвеша с большей точностью. Чувствительность к сигналу можно повышать далее с помощью обычных электронных методов.