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LVI. *Instruments for Measuring Small Strains in Bars Subjected to Twist.* By E. G. COKER, B.A., B.Sc., M.I.M.E., Late Scholar of Peterhouse, Cambridge*.

THE advances made within recent years in the scientific testing of engineering materials have caused great attention to be paid to the design of instruments for measuring small strains. By far the greater number of such instruments have been devised for measuring the small strains of extension or compression in bars subjected to a direct pull or push; and but little attention has been paid to instruments for the use of engineers in the measurement of the small strains in a bar subjected to twist.

The object of the present paper is to describe two arrangements of apparatus intended for use in engineering laboratories and testing-houses for measuring such strains, and for the determination of the Modulus of Rigidity.

Each instrument is wholly supported by the test-bar, being secured thereto by screws which grip the bar at two transverse sections separated by a known interval, and the relative angular displacement between these two sections is measured directly. The instruments are adapted to measure both large and small strains, and are self-contained, while they can be used in a horizontal, vertical, or inclined position.

One form of the apparatus is shown by fig. 1, and consists of a graduated circle, A, mounted upon a chuck-plate, B, provided with three centering-screws adjustable by hand. A ring, C, secured to the test-bar by set screws at a known distance away carries a swivel-arm, D, in which slides a tube, E, so that the contact-ball, F, at its outer end can be brought into position touching the centre of the faced end of a screw-micrometer gauge, H, provided with a divided head. This micrometer-screw is mounted upon a vernier-plate, J, of the graduated circle, and can be clamped in any position, the final adjustment being effected by a screw N.

A silk-covered wire connects an insulated binding-screw, K, upon the ring with the contact-ball, and this wire is joined up in circuit with a simple form of galvanometer, L, and cell, M, to a second uninsulated binding-screw on the ring. If the contacting pieces are touching, a circuit is completed through the test-bar, and the galvanometer-needle is deflected. If now a twisting movement is applied to one end of the test-bar, the contacting pieces are separated, and the micrometer-screw must be advanced until the circuit is

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again completed as indicated by the galvanometer-needle. The number of divisions through which the screw has been turned affords a measure of the angular displacement, and it only remains to calibrate these readings in terms of angular measurement.

Fig. 1.

The calibration is effected by reference to the graduated circle and vernier-plate.

The micrometer-screw is set tangentially to the radial arm, and therefore its indications are nearly proportional to the tangent of the angle moved through; but if the faced end of the screw is always maintained at or about its central position, the error introduced by taking the readings as directly proportional to the angular displacement is relatively small compared with the quantity under measurement, and may be neglected.

To calibrate the instrument it is therefore only necessary to measure the number of divisions corresponding to a small angular displacement of, say, $10'$; and this is easily accomplished by setting the instrument in position with the circuit complete, and afterwards following up a known angular displacement of the vernier-plate by the micrometer-screw.

A simple form of detector-galvanometer, in circuit with a single dry cell, has been found to be a convenient arrangement for indicating when contact takes place, and the feeble current required does not injure the contacting surfaces.

It is essential that the graduated circle be set accurately upon the bar, with its plane perpendicular thereto and its centre coinciding with the longitudinal axis of the bar. An arrangement has been devised to effect this, consisting of two similar and equal clamp-bars, the eyed ends of which take over outwardly projecting cones arranged diametrically upon the chuck-plate and ring. Each main piece has one degree of freedom with respect to the clamp-bars, and therefore two degrees of freedom with respect to the other; these degrees of freedom are suppressed by projecting plates fitting against corresponding projections on the main pieces; and this connexion makes the apparatus a rigid whole. The bar is now inserted and the screws adjusted by hand as accurately as possible.

The clamp-bars are afterwards removed, leaving the two main pieces accurately spaced on the bar, while the graduated circle remains perpendicular thereto and very approximately centred. The light contacting arm is then clamped in position, and the bar may now be set in the testing machine.

An improved clamp described with reference to the second form of apparatus may be used instead of the arrangement described above, and the hand-operated chuck-plate may be replaced by a form of self-centering chuck described below. An example of tests made with this apparatus is given below.

The test-bar was adjustably secured at one end and a balanced lever of fixed length secured upon the free end, and hung from the arm of a scale-beam. The load was applied by placing equal weights in the suspended pans of the balanced lever and scale-beam, so that bending movement was as far as possible eliminated. Before making a reading the torsion-arm was brought to a horizontal position by aid of a spirit-level.

The mean of the calibration tests gave $18\cdot6$ divisions of the micrometer-screw as corresponding to an angular displacement of 1 minute of arc.

Turned bar of Bessemer steel, length under measurement = 10·25 inches, diameter = 0·747 inches, torsion-arm = 15 inches, a constant.

The figures in the first column give the load in the pan at the end of a constant arm.

Load, lbs.	Reading.	Differences.
0.....	0	
1.....	26	26
2.....	51	25
3.....	77	26
4.....	103	26
5.....	128	25
6.....	154	26
7.....	179	25
8.....	205	26
9.....	231	26
10.....	256	25
11.....	283	27
12.....	307	24
13.....	333	26
14.....	358	25
15.....	384	26
16.....	410	26
17.....	435	25
18.....	460	25
19.....	485	25
20.....	510	25

If l = length of the bar,

d = diameter,

T_m = twisting-moment,

θ = relative angular displacement,

C = modulus of rigidity.

Then for bars of uniform circular section

$$C = \frac{32T_m l}{\pi d^4 \theta};$$

and we have for this test-bar

$$C = 11,790,000 \text{ lb. per square inch.}$$

A second test gave almost identically the same results.

The performance of the instrument is limited by the accuracy of the micrometer-screw, and in the present instrument the smallest angular displacement capable of measurement is about four seconds of arc. As the contacting bar is not heavy, no difficulty is experienced in balancing it, and therefore its length may be considerable. This form of instrument is therefore adapted for measuring the strains in long test-bars.

The second form of apparatus differs from the preceding in

employing a reading-microscope to observe the relative angular displacement of a radial line upon the vernier-plate. The edge of a thick wire is a very convenient line for observation, and has been used with notable success in an extensometer designed by Professor Ewing (Proc. Roy. Soc. May 1895). The instrument is shown by fig. 2, in which A is the graduated

Fig. 2.

circle mounted upon a chuck, B, and furnished with a vernier-plate, J, an arm, O, of which carries a wire, P.

A reading-microscope is carried in the sleeve, R, of an arm, S, mounted upon the short cylinder, C, which latter is gripped upon the test-bar by screws.

The reading-microscope has an eyepiece, T, provided with a glass scale, and a right-angled prism, U, is interposed between this and the objective, W, so that readings can be easily taken. The tube, Q, is free to slide or rotate in its guide, R; but in order to readily focus the wire this latter is carried in a frame, X, pivoted on the vernier-plate, J, and adjusted by a screw.

The microscope arm, S, is secured to the cylinder, C, by a divided collar, the two halves of which are pivoted on one side and the free ends are clamped by screws. If it is desirable that the telescope be turned round or released altogether,

the screw may be thrown out of engagement. Since the difference between an arc and its corresponding chord is an infinitely small quantity of the third order when the arc is an infinitely small quantity of the first, the readings of the microscope-scale may be taken as directly proportional to the angular displacement, and the calibration is effected by moving the wire through a definite angle of, say, $10'$, and noting the equivalent reading of the micrometer eyepiece.

This instrument is furnished with an improved form of clamp (fig. 3), consisting of a pair of divided collars, *a*, the halves being pivoted together at *b*, and secured by nuts *c*.

Fig. 3.

The collars are wedge-shaped in radial section to engage with corresponding wide-angled grooves upon the chuck-plate and cylinder, only the angled sides being in contact, so that the collars are readily freed when required.

The lower halves, *d*, of the divided collars are connected by one or more distance-pieces, *e*, so that when the former grip their respective grooves each piece has one degree of freedom with respect to the clamp; and this can be suppressed by a pin or by the frictional grip of the collars, thereby causing the parts to act as one rigid whole for setting the instrument on the bar.

The two main parts of the apparatus are set in their respective collars; the bar is then passed through and the screws adjusted. The clamp is then removed, leaving the two pieces at the correct distance apart, while the graduated circle has its plane perpendicular to the bar, and is chucked accurately thereon.

The graduated circle of this instrument is carried by a self-centering chuck of somewhat novel form, and a section through this is shown by fig. 4, while a perspective view of the arrangement is shown by fig. 5.

There are three centering-screws, *A'*, the outer cylindrical ends of which are supported in guides, *B'*, and prevented from
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Fig. 4.

Fig. 5.

rotating by pins, C', engaging with slots, S', cut in the screws. The screws work in rotating nuts, D', provided with bevel pinions, E', gearing with a hand-operated bevel ring, G', so that all the screws are advanced or receded together. An additional pinion, H', is provided, operated by a key fitting on its squared spindle, J', so that the screws are firmly gripped upon the bar. The inner ends of the nuts have a collar-bearing, K', so that the stresses are borne by the body, L', of the chuck, and the bevel ring is prevented from seizing by bearing-plates and an adjustable ring, M', at the back. This bevel ring can be slid back to allow any screw to be separately adjusted. Other modified arrangements of the chuck have been tried in which the guide-pins have passed bodily through slots cut through the inner ends of the screw, and the screw pairs have been inverted; but these modifications have not answered well.

An example of tests made with this form of apparatus is appended, the same Bessemer steel bar being used.

Mean value of calibration-test—1 minute of arc corresponds to 36 divisions of scale.

Length under measurement 8 inches, diameter 0.747 inches, torsion-arm 15 inches, a constant.

Load, lbs.	Reading.	Differences.
0.....	800	
1.....	759	41
2.....	718	41
3.....	677	41
4.....	636	41
5.....	596	40
6.....	555	41
7.....	513	42
8.....	471	42
9.....	430	41
10.....	389	41
11.....	349	40
12.....	309	40
13.....	267	42
14.....	225	42
15.....	183	42
16.....	143	40
17.....	103	40
18.....	62	41

And we have for this test-bar $C = 11,850,000$ lb. per square inch.

A second test gave very approximately the same result. Angular displacements of 1" can be measured with this form of apparatus. As the overhanging arm carrying the micro-

scope is necessarily heavy to afford the requisite stiffness, the length under measurement is limited.

For the purpose of making the angular displacements visible to an audience a magnifying arrangement is used, consisting of a tilting mirror supported upon a tripod. Two legs of the tripod are supported by a hole and slot carried upon the vernier-plate, and the third leg is supported upon a plane attached to the other main piece.

The spot of light reflected from the mirror is caused to move over a fixed graduated scale, and the angular displacement is thereby made visible.

LVII. *On the Charge of Electricity carried by the Ions produced by Röntgen Rays.* By J. J. THOMSON, M.A., F.R.S., Cavendish Professor of Experimental Physics, Cambridge*.

THE following experiments were made in order to determine the magnitude of the charge of electricity carried by the ions which are produced when Röntgen rays pass through a gas.

The theory of the method used is as follows:—By measuring the current passing through a gas exposed to Röntgen rays and acted upon by a known electromotive force, we determine the value of the product nev , where n is the number of ions in unit volume of the gas, e the charge on an ion, and v the mean velocity of the positive and negative ions under the electromotive force to which they are exposed.

Mr. Rutherford (Phil. Mag. vol. xliv. p. 422, 1897) has determined the value of v for a considerable number of gases; using these values, the measurement of the current through a gas gives us the product ne ; hence if we can determine n , we can deduce the value of e .

The method I have employed to determine n is founded on the discovery made by Mr. C. T. R. Wilson (Phil. Trans. A, 1897, p. 265) that when Röntgen rays pass through dust-free air a cloud is produced by an expansion which is incapable of producing cloudy condensation when the gas is not exposed to these rays. When a determinate expansion is suddenly produced in dust-free air a definite and calculable amount of water is deposited in consequence of the lowering of the temperature of the air by adiabatic expansion. When the gas is exposed to the rays the ions caused by the rays seem to act as nuclei around which the water condenses. I have shown ('Applications of Dynamics to Physics and Chemistry,' p. 164) that on a charged sphere of less than a certain

* Communicated by the Author.