at a load equivalent to 11.7 tons per sq. in. of original metal. This, of course, is a low value, but still is of interest as showing that there was a considerable strength (say, about 40 per cent.) in the weld, even though it could be broken off by a very slight transverse stress. A similar test piece was cut from Drum F, and broke with a load of 15.4 tons per sq. in., but the fracture occurred close up to the grips of the testing machine, and not at the weld. The figure obtained is, of course, not very significant as a test of the material, since a test piece prepared in the way described, owing to its irregularity of shape, would not be expected to develop the full strength of the material. The result is, however, of some value as showing that the weld would at least stand a stress of 15 tons per sq. in. This last-described test piece was then placed in a vise with the weld just protruding, and a transverse pressure of a pound or two on the other end was sufficient to break the weld. It must be remembered that this longitudinal weld is a simple butt weld, with no filling material, and if the welds are examined it will be found that it is only at certain places along the length of the weld that the two butted faces are welded throughout their full thickness, the intervening lengths being only partly welded—sometimes for not more than a third of their thickness, and these places where the welding does not go right through are, of course, distinct spots of weakness. Assuming that the efficiency of the weld would be some figure, say, of the order of 80 per cent. at places where the weld is solid, the efficiency would be very much reduced wherever the welding had not gone right through from the outer surface of the drum to the inner surface; so that it would be possible to find sections of the welded joint with an efficiency of not more than 20 or 30 per cent. This was illustrated by cutting out a piece of the longitudinal weld from one of the drums about 12 inches long, that is to say, a piece of the metal was obtained with 12 inches of longitudinal weld right down its centre. On one side, corresponding to the outer surface of the drum, the weld showed the characteristic "pooling"; on the other side (i.e., the inside surface of the drum) there were two or three short lengths showing the "blobs" of metal where the welding had gone right through the thickness, these being separated by short portions of the joint showing no welding at all. This test specimen was then placed in a vise with the 12-inch length of weld just protruding, and the top part was gripped with a wrench and the weld by that means racked backwards and forwards. The weld was found to "hold on" with great tenacity at all the places where the welding had gone right through the thickness, but opened at the places where the welding was imperfect. It appears to be difficult to ensure that long lengths of simple butt welding should be carried completely through the thickness of the metal, and allowance must be made for this in estimating the strength of such a drum.

The general conclusion to which these various experiments would lead is, that when subject to a simple tension such as might be looked for in the longitudinal weld of a drum, the welded joint would be able to withstand the stress so long as the appropriate deduction were made for the fact that the full area of the plate is probably not available. This would, of course, be in addition to the deduction made in the ordinary way by the use of a coefficient to represent the efficiency of the joint. On the other hand, such joints are not suited at all to withstand anything in the nature of a transverse strain, and considerable care should therefore be exercised in adopting them in circumstances where the drums may be subjected to hard usage; say, by being dropped.

10. *Strength of Ring Welds and Dished Ends.*—On the whole, the experiments on the bursting strength of the drums leads to the conclusion that the welded ring joints at the ends of the drums, i.e., the joints between the cylindrical portion and the concave dished ends, are the weakest spots. Although Drum A failed by fracturing along the longitudinal joint, yet all the other tests to destruction which were tried on similar drums resulted in failure at the ring joints. There are very heavy cross strains produced here by the tendency of the concave ends to bulge outwards, and when the end has actually bulged to the convex shape the ring joint tends still more to tear open. Under ordinary circumstances it appears fairly clear that drums of the particular design and dimensions under consideration will bulge at the ends when the pressure is in the neighbourhood of 80 or 90 lbs. per sq. in., and leakage will commence somewhere in the neighbourhood of 100 to 110 lbs. per sq. in. owing to the opening of the ring weld joint. For the purpose of carrying acid this preliminary giving way of the concave ends may be looked upon as an element of security, since the bulging at the ends greatly increases the volume of the drum, and thereby lowers the pressure inside the drum and allows of the drum being neglected for a considerably longer period before the pressure becomes such as to break the joint. In the case of Drum A, the failure along the longitudinal joint rather than at the end was due to an unusually great proportion of the longitudinal joint having failed to weld right through the thickness of the metal. There was also a dent showing in the side of the drum in the neighbourhood of the fracture, which indicates that the drum may have been allowed to drop on to some hard object, thus putting a transverse strain on the already weak joint which it was unable to resist. When such drums are turned out in large quantities, it can only be by the most

careful inspection of each drum during the process of manufacture that the risk of such a partially-welded joint occurring can be avoided.

11. *Factor of Safety Recommended.*—It can readily be appreciated that under the circumstances mentioned in the foregoing sections, a large factor of safety should be used with welded drums if the chance of their failing involves serious risks to life and property. If, under ordinary circumstances, a factor of safety of 5 would be regarded as satisfactory, it should be remembered that the factor ought not to be applied until the stress in the material of the joint has been computed by using a suitable coefficient of efficiency for the joint, say, not more than 80 per cent., and then another coefficient depending upon the amount of the butted surfaces which it can safely be assumed have been actually welded together. As has been shown, this second factor might be as low as 30 or 40 per cent.; or, putting the matter in another way, the actual efficiency of the joint might have to be taken as low as, say, 25 per cent. instead of 80 per cent. This would be equivalent to using a factor of safety of 20 on the original strength of the metal; but where a risk to life is involved, it is questionable if one would be justified in allowing a less margin of safety with joints similar to those now under discussion. The more minute the inspection during the course of manufacture, of course the less would be the risk, and the actual factor adopted must be determined entirely in view of the skill of the operator and the vigilance of the inspector.

12. *Use of Proof Pressures.*—The foregoing argument only serves to emphasise what has so often been stated —that the use of proof pressures in specifications is of practically no value, apart from showing that the drum is tight, and will not leak up to the proof pressure decided on. Absolutely no information of any kind is afforded

by the test, and to adopt such a test is merely to encourage a fallacious sense of security which has no foundation whatever in fact.

SECTION C.

13. *Strains on the Surface of the Drum when under pressure.*—The enquiries described in the foregoing sections suggested that it might be useful to make a complete series of experiments to measure the strains produced all over the surface of the drum when under pressure. It was thought that such an enquiry might show what was the general method of straining such a drum, whether the strains produced were at all regular in similar parts of the drum, and how far the strains produced could be

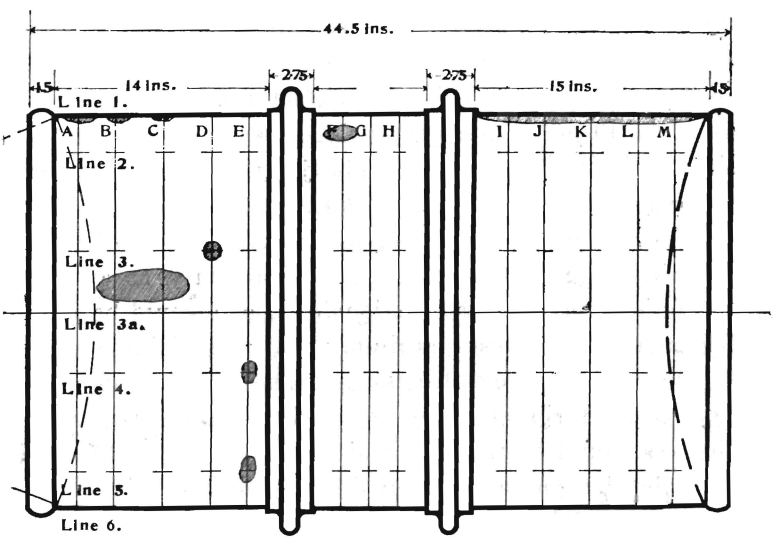

FIG. 7.—Drum F, showing longitudinal test lines 1 to 6, and circumferential test lines A to M. The shaded areas represent the positions of slight dents.

used as measures of the stresses. The authors thought at first that it would be probably more instructive to use one of the ordinary service drums, even though it showed a few slight dents and irregularities, since it would be interesting to know how far the latter affected the strains produced. The results obtained, however, indicated that it would have been wiser to select a drum as perfect in form as possible, since it will be seen that the effects of the irregularities were so great as to, in some places, entirely modify the normal action. The general plan followed was to determine, at a pressure of 30 lbs. per sq. inch, the strains (1) on the drum's surface with particular regard to the weld, (2) on the concave dished ends and (3) the strains in all directions at certain selected points on the drum's surface.

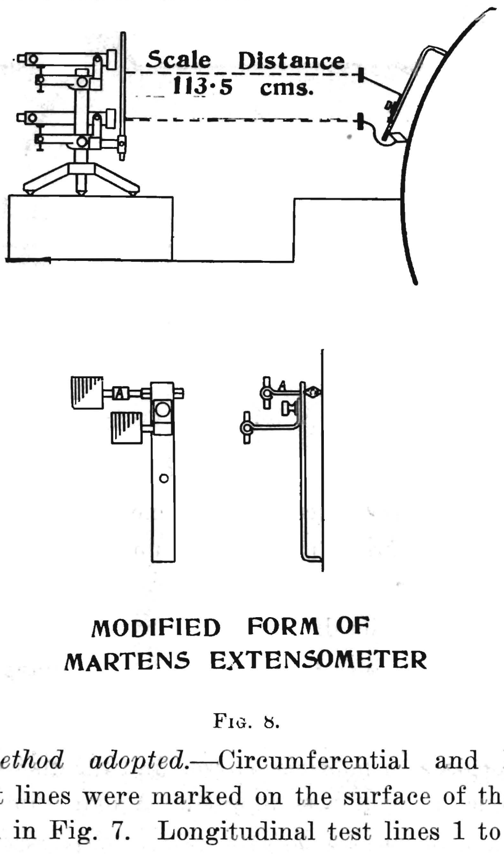

Fig. 8.

14. *Method adopted.*—Circumferential and longitudinal test lines were marked on the surface of the drum, as shown in Fig. 7. Longitudinal test lines 1 to 6 were spaced symmetrically round the semi-circumference of the

drum, with an additional one, 3a, intermediate between the lines 3 and 4; while the circumferential lines A to M divided the length of the drum, as indicated by the dimensions in Fig. 7. By now measuring the actual strains in a longitudinal and circumferential direction at each point marked by the intersection of these two series of test lines, it was possible to obtain approximate curves showing the strain along any longitudinal or circumferential section. A similar method was adopted as regards the dished ends, circular test lines being scribed, as shown in Fig. 13.

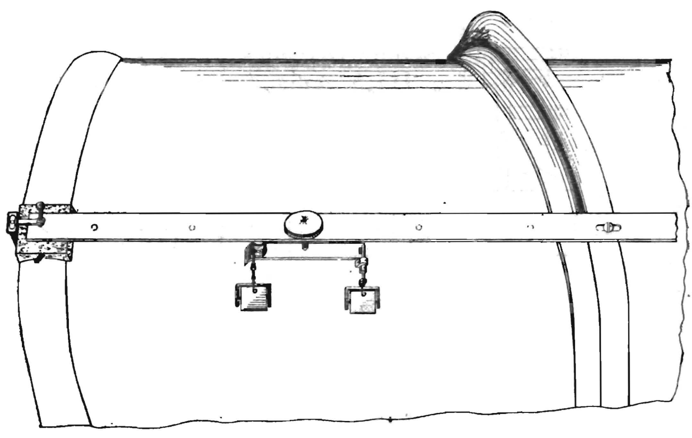

FIG. 9.—Diagram showing method of applying Martens' Extensometer.

The strains were measured by means of the extensometer* of Dr. Martens, slightly modified, as shown in Fig. 8.

The length of the distance piece was, approximately, 2 inches (5 cms.), this short length being adopted so that the curvature of the drum should produce no appreciable effect. The following method of applying pressure to the distance piece to hold the mirror and distance piece on any particular spot was adopted. A long thin steel bar

* It is unnecessary to describe this extensometer in detail as a fuller account of it was published in the *Proceedings of the Engineering Association*, Vol. XVI, page 303.

¾ of an inch by ⅛ of an inch was placed over the roller bands of the drum and secured firmly, though not rigidly to the drum by small cup screws which fitted slots in the bar. Holes were tapped in the bar along its length to correspond to the points marked on the drum, and a thumb screw at these points held the distance piece and mirror up to the drum's surface. (See Fig. 9.)

During these experiments the pressure was not allowed to rise higher than 30 lbs. per sq. inch so as to avoid the possibility of causing a permanent set in any part of the drum. The strains were measured from 5 lbs. per sq. inch up to 30 lbs., and from the curves plotted therefrom the figures at 30 lbs. per sq. inch were read off. An immense number of such observations was taken, and a typical example is shown in Fig. 10.

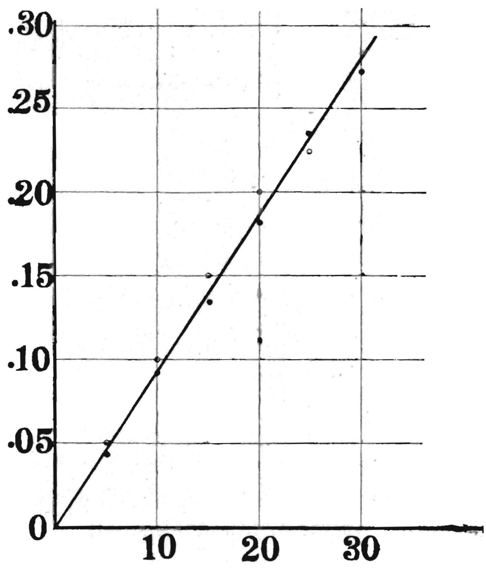

Fig. 10.—A typical curve showing strains (scale readings, cms.) produced by pressure in drum up to 30 lbs. per square inch. Dots show ascending readings and circles descending readings.

15. *Results obtained.*—It is probably not worth while to attempt to give even a summary of all the measurements taken, since they apply only to this particular drum, and owing to slight irregularities in its shape they would not have any general application. Hence two sample curves only are reproduced. In Fig. 11 is shown

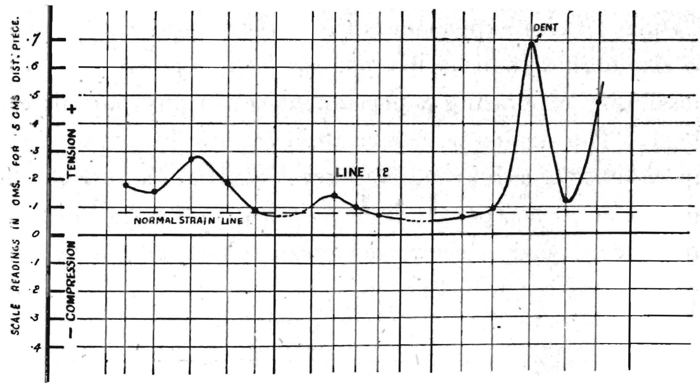

FIG. 11.—Curve of longitudinal strains obtained along line 2.

the longitudinal strain curve for line 2, and in Fig. 12 the circumferential strains for the tests lines A, C, D, and E, the figures for the lines A and C being plotted to the right of the vertical, and those for lines D and E to the left of the vertical. As regards longitudinal strains the curves are instructive as demonstrating the following points:—(a) Lack of symmetry from end to end of the drum; (b) divergence from the normal or theoretical strain line, and (c) the effect of dents and irregularities in the drum's surface. Similar observations hold with regard to the circumferential strains, although the divergence from the normal is not so marked except in the neighbourhood of the weld, where the strains are very heavy.

16. *Strains at any individual point.*—The strains hitherto referred to are measured either longitudinally, i.e., parallel to the axis of the drum, or circumferentially. There are, of course, strains in all other directions intermediate between these two, and it seemed a matter of interest to determine these strains in all directions for

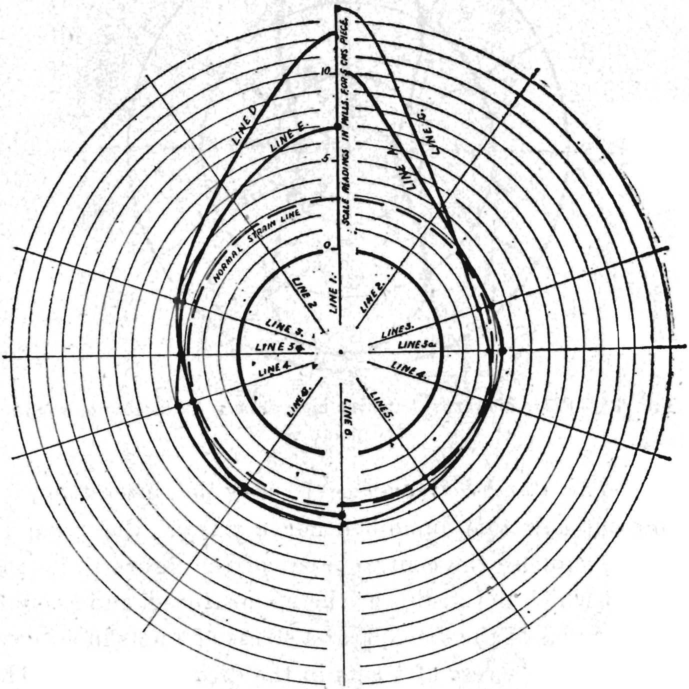

FIG. 12.—Curves of circumferential strain showing the strains measured on lines A, C, D and E.

selected points on the surface of the drum. This was done at the points C, G. K of line 6, which is the line remote from the weld, and the results for one of them, viz., point G, are given in the accompanying diagram. It can be seen that the strains were measured along twelve lines, the distance piece of the Martens' mirror being moved round its central point from one position to the next until it returned to its original position. The curve obtained is fairly symmetrical, and is of a characteristic dumb-bell shape (see Fig. 13).

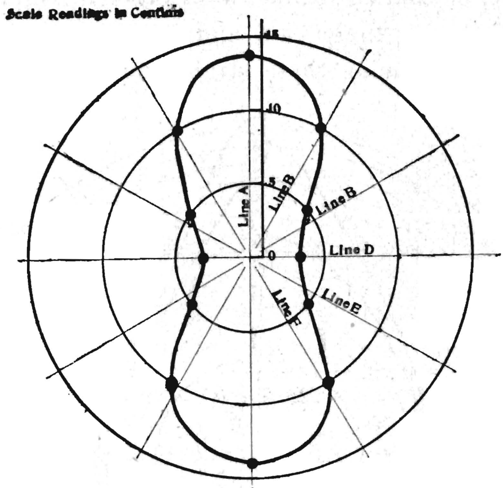

FIG. 13.—Polar diagram of strains measured in all directions round the point G.

17. *The dumb-bell curve.*—It may be interesting to point out how this dumb-bell curve arises. Referring to Fig. 14, suppose the central point of the figure to be the point at which the strains are being measured, and assume, as in the case of the drum, that a stress of 2 acts in a direction *bb*, and a stress of 1 acts in the direction of *aa*. The strain in the direction of *bb* will be proportional to a stress of 2 less an amount dependent on the contraction due to the stress in the direction *aa* acting at right angles to it, and similarly the strain in the direction *aa* will be proportional to a stress of 1 less an amount dependent upon the contraction due to the stress in the direction *bb* at right angles to it. These strains have been plotted at *bB* and *aA* to an exaggerated scale, using a value of Poisson's ratio of .25. In fact the circle *abab*

on the surface would become the ellipse *ABAB*. Plotting the intercepts between these two curves for a still further exaggerated scale for convenience, from the central point of the figure, the dumb-bell curve *aPaP* is

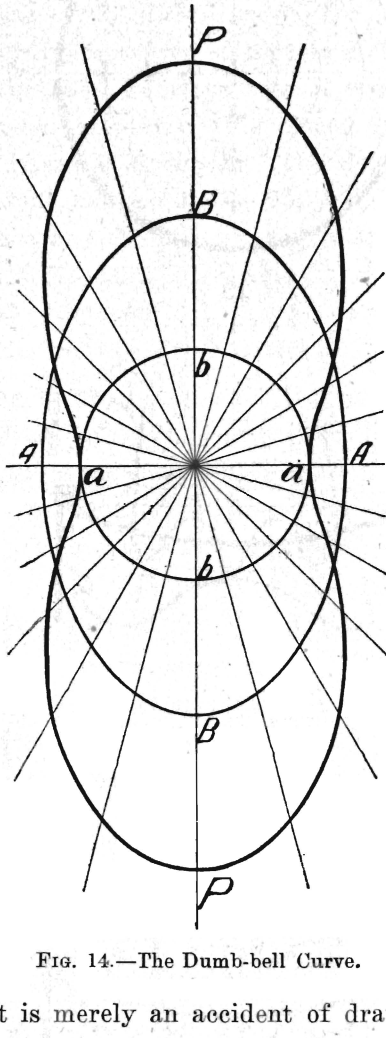

FIG. 14.—The Dumb-bell Curve.

obtained. It is merely an accident of drawing that the dumb-bell curve happens to touch the circle. The particular shape of the dumb-bell figure will obviously de-

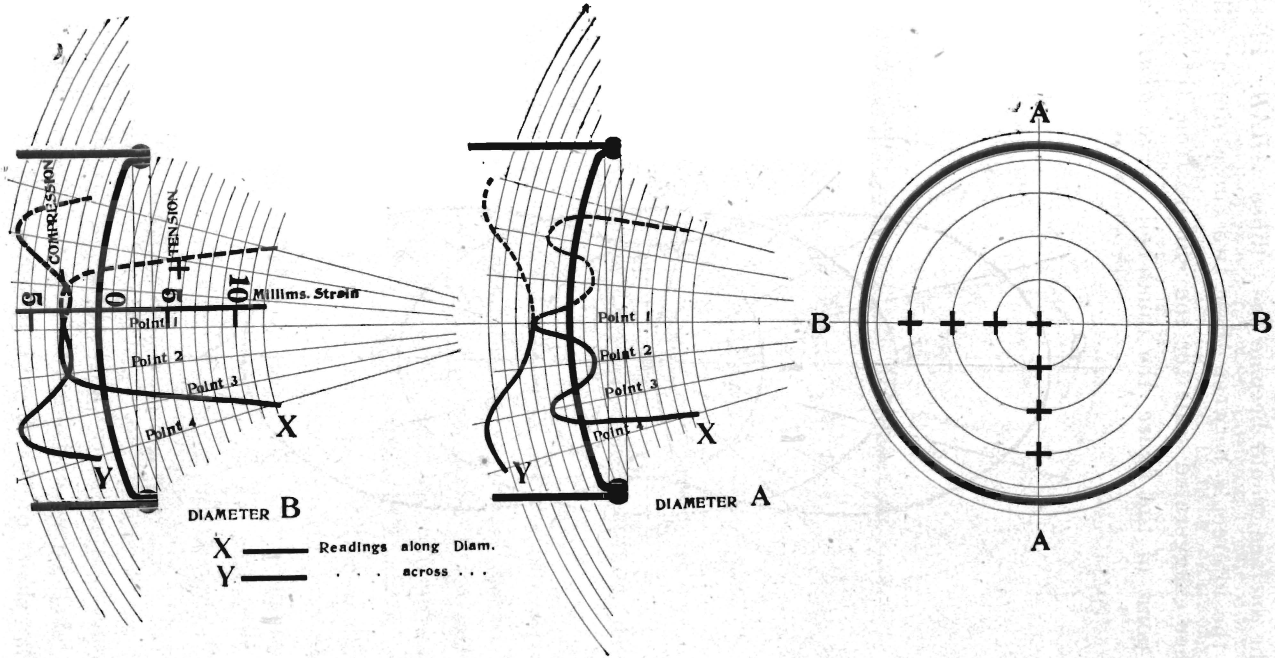

FIG. 15.—Curves of strain on dished ends. The fourteen short black lines on the right-hand diagram show the positions of the distance pieces for the respective series of observations.

pend on the value for Poisson's ratio. Obviously this is an experimental method which might be used for determining that ratio and also all the other elastic constants of the material.

18. *Strains in the dished ends.*—The strains in the dished ends were measured along two diameters *AA* and *BB*. (See Fig 15.) Fourteen sets of observations were taken, the distance pieces being placed as shown in the right-hand diagram of Fig. 15. The strains are plotted in the left-hand diagram of Fig. 15, those measured radially being marked X, and those measured tangentially being marked Y. It is interesting to note the contraflexure on the diameter *AA*, this probably being caused by a slight dent in the surface along the latter diameter.

Arrangements are being made to repeat a number of the observations referred to in this section of the paper on a carefully constructed drum of simple design, so as to make the problem of comparing the results obtained with those which would be theoretically expected less complicated.

19. *Acknowledgments.*—In conclusion, the authors desire to thank Mr. Kennedy for making the test welds referred to in the first section of the paper, and also to thank Professor Warren for enabling the tests of the material to be carried out.

Discussion.

Mr. Shirra said that he supposed they were all pretty well familiar with the oxy-acetylene process, which had now attained considerable popularity, even among amateurs. The results put before them by the lecturer were,