zigzag riveting. It would only have shown that the closer pitch was superior to the wider one, owing to the strains being more equally distributed and the extension more localised. The close chain riveting simply enabled the full strength of the metal left between the rivet-holes to be utilized, but there was no reason for doubting that with a zigzag joint of equal pitch the same result would have been obtained. On the contrary, as zigzag riveting appeared from its form better adapted than chain riveting for equalizing the strains along the lap of a plate, it was more than probable that a well-arranged zigzag joint was capable, with a somewhat wider pitch than chain riveting, of utilizing the full strength of the metal left between the rivet-holes, and thus of affording a higher ratio of strength of joint. Mr. Smart.

The Author entirely agreed with Mr. Samson Fox with regard to the superior strength of the corrugated flue to resist collapse both before and after pocketing; but the recommendation to close staying was made in consequence of instances having come to his knowledge of the elongation referred to. He wished, however, to take this opportunity of mentioning that, since the Paper was written, instances had been reported in which close staying of marine corrugated furnaces, of the thickness and consequent stiffness now necessary for the high pressures coming into use, had produced too great rigidity, and had given trouble by causing leakage at the joints. It would therefore be seen that there was a possibility of overdoing the closeness of the staying, notwithstanding the pliancy of the flues under compression claimed for them by Mr. Fox.

Apparently it was sometimes thought that the expansion of a corrugated flue of a given length by heat alone, and independent of the elongation due to the pressure on the end plates, would be greater than that of a plain flue of similar length; but this would not be the case, the amount of expansion in each instance would be the same, notwithstanding the greater length of metal in the corrugated flue.

Correspondence.

Mr. George P. Culverwell observed that previous to leaving the makers boilers were now almost always tested, firstly, by hydraulic power, and, secondly, under steam at pressures considerably in excess of the intended working limit. There was a tendency, not only with the general public but also among some engineers, to Mr. Culverwell.

Mr. Culverwell. view such tests as finally indicative of satisfactory strength or otherwise. The satisfactory strength of a boiler could only be guaranteed by the fulfilment of three conditions, namely, by good quality of the materials, by proper design and proportionment of parts, and by good workmanship. Hydraulic and steam-tests had reference merely to the latter. He had known instances, however, in which unduly high tests had been specified, whereby the joints would become permanently stressed. In such boilers as he had tested he was careful to avoid this, and he considered there was no advantage in exceeding the working-limit by more than 40 per cent. The tests should be maintained for some time, say, for fifteen minutes or longer, so as to allow water in deep double-riveted seams to creep through and show itself. He noted the Author's remark that some firms of good reputation neither fullered nor calked the seams, but relied altogether on good workmanship. In any case he would recommend that the hydraulic and steam tests be applied previous to any outside calking or fullering, otherwise there would be no guarantee that water was not lying in the joints.

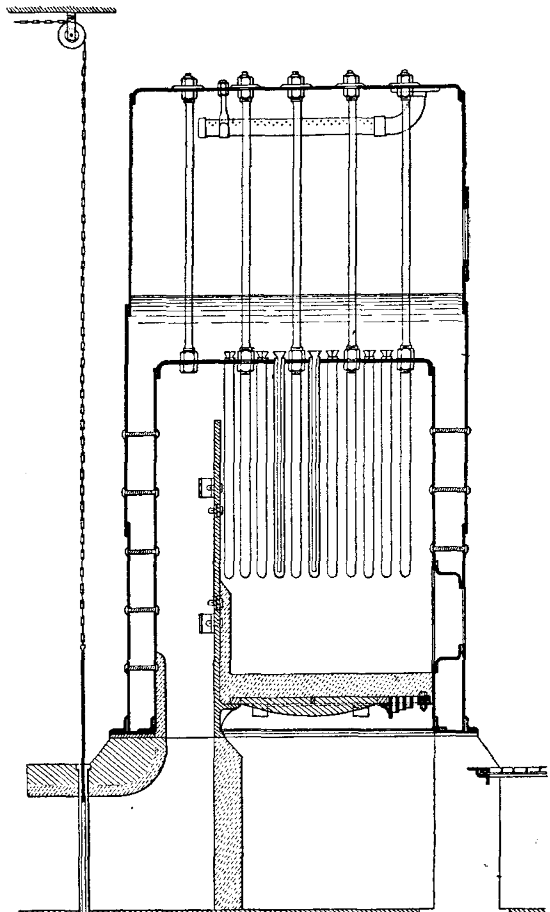
Mr. Hayes. Mr. John Hayes directed attention to what he considered a serious defect in the detail construction of steam-boilers, especially of the locomotive and vertical type. By reference to Fig. 10 it would be seen that, in the type of vertical boiler put forward by the Author, the plates of the firebox, both at the fire-hole door opening and at the bottom or foundation of the firebox, were worked or dished out to meet the plates of the outer casing or fire-box shell; this was bad boiler construction, and therefore to be discountenanced, as the aim of an engineer in designing a boiler should be, and was in first-class work, never to bend, work, or flange any plate, especially a firebox-plate, unless the same was from constructive or other difficulties absolutely necessary. In his opinion, the proper mode in this case was to put in solid wrought-iron rings of the full width of the water-space between the inner and the outer casing, both at the fire-hole opening, but more especially for the bottom or foundation ring of the firebox. The many advantages attending the use of solid intervening rings were so obvious, in place of bending the plates themselves, that further explanations would be superfluous; all the best locomotive and boiler-making firms inserted solid rings, and left the firebox plates straight. The only reason for the contrary being adopted was that it was somewhat less costly, and boilers so put together were made "to sell," their safety and working efficiency being only of secondary importance, hence the trouble and disaster so frequently attending their use. Many of the evils attending the working of stationary boilers, and the destruction caused by boilers being allowed to get "short of water," could be reduced to a minimum, if not entirely prevented, by the adoption of some simple and efficient means of supplying boilers with water "automatically." This was no mere theory; he had for the past two years put the matter into practice by means of the Fromentin Automatic Boiler-Feeder, which he had successfully fitted to boilers in various parts of the country. Stated briefly, its functions were to maintain by automatic means a constant water-level in any steam-boiler to which it was fitted, irrespective of the rate of evaporation; shortness of water was therefore impossible. It was also a means by which, at the same time, the water passing into the boiler might be measured, and was a simple, ingenious, and trustworthy piece of mechanism for the purpose of boiler-feeding. Mr. Hayes.

Mr. C. H. Moberly observed that the Author simply stated the fact that the steel plates used for boilers had a tensile breaking-strength of 26 to 30 tons per square inch. These limits were very properly fixed some years ago, and were now the standards used by Government and most users of steel plates. But he thought an endeavour should be made to raise the standard of strength, if this could be done with safety, in order to reap the full advantages of such an excellent material as mild steel. He had reason to believe that there would not be any difficulty in getting steel makers to produce steel plates and rivets of a tensile breaking strength of 29 to 31 tons per square inch, with an extension of 25 per cent. (or possibly a little less) in 10 inches, and, furthermore, of such quality that the steel should not harden if plunged red hot into water. This steel would be rather harder than that of lower tensile strength; but he contended that that was a positive gain, because it enabled the riveted joints of the steel plates to be made all the stronger. In furnace work the softer steel of course remained preferable. He had repeatedly found such harder steel in every way satisfactory. Rivets must, of course, be of the same quality, otherwise little advantage would be gained. The Author mentioned gusset-stays for the ends of boilers, attached by single or double angles to the shell or end-plates. He also mentioned the longitudinal stay-bolts for the ends, and Mr. Fletcher explained that these stay-bolts should be fixed with a considerable amount of sag, so as to allow the ends of the boiler to go outwards a little by expansion of the flue before they come into play. It was admitted on all hands that the ends must Mr. Moberly.

Mr. Moberly. be sufficiently flexible to allow of the necessary breathing action, caused by the differences in temperature between the several parts of the boiler. For this reason he considered the gussets attached by angles too rigid, whilst the method of preventing the rigidity of the stay-bolts by making them sag when cold, seemed very crude and unsatisfactory. At Erith, Messrs. Easton and Anderson had always adopted flanged gusset-stays, riveted to end- and shell-plates with a single row of rivets. They formerly made these of treble-worked Staffordshire plates; but of late years they had used steel plates. The riveting of these gussets had to be very carefully done to prevent leakage. But this difficulty being got over, the gussets answered admirably and lasted many years. They yielded in course of time to the repeated bending in the root of the flange. It was then an easy matter to substitute new gussets for the old ones. The Author had alluded briefly to the various forms of riveted joint. There was much need of accurate information on this subject, and he hoped some additional information would be forthcoming. The Research Committee of the Institution of Mechanical Engineers had done good service in devising riveted joints for steel plates, and he trusted would, before long, definitely fix the best form of such joints. But he feared riveted joints for iron plates were, as yet, far from being correctly proportioned. It was hardly fair to give the relative strengths of the different kinds of joints and the solid plates before the best proportions of such joints had been determined.

Mr. Olrick. Mr. Harry Olrick observed that the table of riveted joints would have been more valuable if the comparative strength of plates, both of steel and iron with punched and drilled holes, had been given from actual experiment. He doubted the superior strength of drilled over punched holes unless they were countersunk and the burrs were removed after drilling. He knew of one large railroad shop, about to make steel boilers, which would not be fitted with drilling-machines. His experience was that steel plates from first-class makers were more trustworthy and more readily worked than iron plates costing the same money. The joint (No. 9) shown by the Author as having the greatest calculated strength, namely, 80 per cent., had the outer row of rivets so far apart that he thought the plate could not be fullered or calked efficiently, in case of leakage. With respect to the difficulty of keeping tubes tight when held rigidly at both ends, as in locomotive or marine boilers, he suggested that if torpedo-boat boilers were made up of a number of rectangular vessels fitted with "Field" tubes, which were fixed at one end only, no trouble would occur; and, moreover, boilers so constructed would weigh less, and take up smaller space than a locomotive boiler of the same power. Mr. Olrick considered that a brick or clay lining around the fire-box on the top of the bars was much more necessary than a fire-clay lining to the Mr. Olrick.

Fig. 30.



Scale, $\frac{1}{40}$.

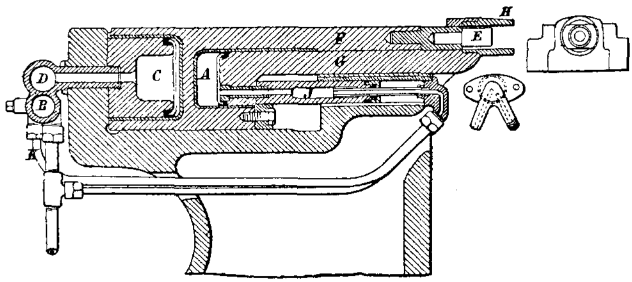
uptake of an ordinary cross-tube boiler, as his experience tended to show that this was the part of a vertical boiler to first show signs of distress, owing to the mud and other impurities in the water silting up the water-space at the bottom of the boiler, and causing

Mr. Olrick. overheating of the plates. For this reason he considered the space from the fire-bar level to the bottom of the water-space, as shown in Fig. 10, much too little. He had designed and built two boilers for the London Stock Exchange, to drive the electric-light machinery (Fig. 30). This form of boiler had no central uptake, and was less liable to damage from expansion and contraction than any other form of which he knew; and at the same time every part of both the inside and out was readily accessible for examination and repairs. This boiler had 400 square feet of surface, and easily drove engines of 60 I.HP., requiring 40 lbs. weight of steam per 1 HP. per hour at 100 lbs. pressure, being only 11 feet 6 inches high by 5 feet 10 inches outside diameter. Tubulous boilers frequently gave trouble, owing to the large quantity of sulphates and carbonates of lime, with other impurities, held in suspension in the feed-water, and which were precipitated when heated to a temperature of 300°. The proper plan to pursue, therefore, was to subject all feed-water to the stated temperature, and to pass it through filters prior to entering the boiler. As this could be done without extra fuel, beyond a very small amount due to radiation, he thought engineers should never neglect to forcibly impress it upon their clients, and so tend to minimize explosions, which were largely due to overheating of plates heavily coated with scale.

Mr. Tweddell. Mr. R. H. TWEDDELL remarked, in reference to the Author's contention as to the necessity of annealing steel plates after flanging, that when hydraulic-machines were employed for this purpose, the work of flanging was performed so rapidly, that the heat which the plate retained was amply sufficient to anneal it without re-heating. The Author had also alluded to the necessity of fitting and bolting the plates well and closely together before riveting them. Mr. Tweddell showed, in Fig. 31, how this was done mechanically by hydraulic pressure, and without any dependence on the skill or attention of the workman. The riveting-machine had two cylinders, one contained within the other. The ram G carrying an annular plate-closing tool H, which surrounded the cupping die E, moved in advance of the ram F, which carried the die E. When the rivet was ready to be closed, pressure was admitted by the valve D into the cylinder C, when the ram F advanced in the usual way. The water in the cylinder A being in constant communication with the accumulator, until the pressure in this chamber exceeded that in the accumulator, owing to the tool H coming against the plate, the full power due to the area of the ram was exerted upon the plates, and they

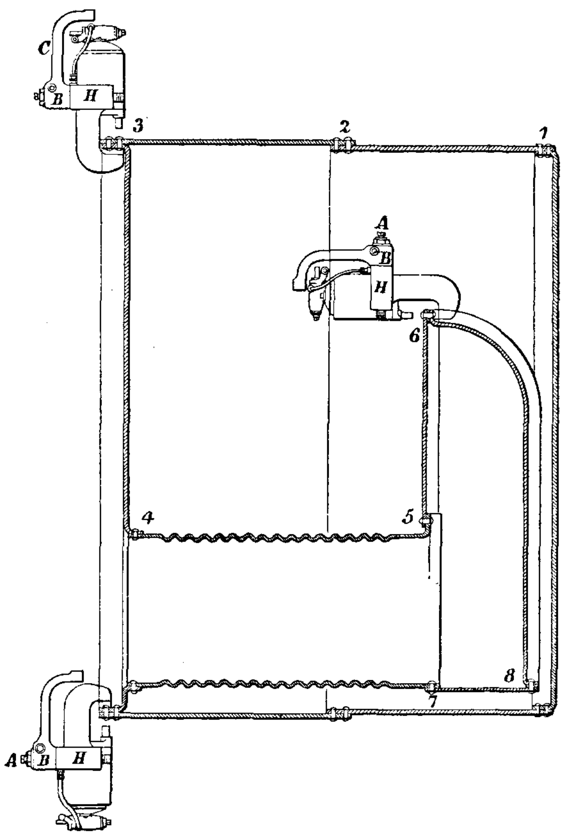
Mr. Tweddell.

FIG. 31.



Scale $\frac{1}{32}$.

FIG. 32.



Scale $\frac{1}{12}$.

Mr. Tweddell. were thus pressed together, before the operation of forming the rivet head began; this also prevented any possibility of the formation of collars or washers between the plates alluded to by the Author. The opposing cupping die in the other arm of the riveter was not shown, but it was of the usual kind, although in some instances the plate-closing gear was put upon this also. The general arrangement of such machines had been fully described in his Paper, read before the Institution in 1883.[1]

In reference to the effects of "punching" on steel plates, it was nearly certain that the action of punches and shears worked by hydraulic pressure was much less injurious to the plates than that of geared machines, and he thought the late Sir William Siemens had stated that the most searching crucial test that this homogeneous metal could be put to, was to punch it.

As to calking, this would be or ought soon to be a forgotten art, and would be less and less required the more mechanical riveting was applied. Fig. 32, p. 183, represented a marine boiler with the plating and joints, so arranged, that all the joints could be closed by hydraulic riveting-machines, some of these joints were such as could not be made tight by hand without being calked; but by means of the portable riveter this could now be done, so that calking was no longer required, and at the most a slight fullering was all that was wanted. He should add, however, that another reason why this was now possible, was the extreme accuracy of the flanged work when effected by machinery. In comparatively light work neither calking nor fullering, as the Author observed, were needed for the reasons above given.

Mr. Webster. Mr. JOHN J. WEBSTER was of opinion that the statement about the comparative strength of plain and corrugated flues needed further explanation, and that full details of the experiments should be given before accepting such extraordinary results. When the corrugated flues were first introduced to the public in 1878, some experiments were made at the works of the Leeds Forge Company, to determine the comparative strength of plain and corrugated flues. A description of the experiments and of the apparatus used was given at the time,[2] and in the absence of further information he assumed that the tubes exhibited at the North-east Coast Exhibition, and alluded to in the Paper, were tested either with the same or similar apparatus, and under similar conditions, the results being equally extraordinary. The apparatus consisted of a

[1] Minutes of Proceedings Inst. C.E., vol. lxxiii., p. 64.
[2] "The Engineer," 29th March, 1878.

Mr. Webster.

cylinder about 8 feet long, made of plates $1\frac{1}{8}$-inch thick, bound with five iron hoops 5 inches by 3 inches, with end-plates 5 inches thick, and stayed longitudinally by external bolts $2\frac{1}{2}$ inches in diameter. This cylinder acted as the shell of an ideal boiler, the end plates being prepared at each extremity to receive the tube or flue to be tested, leaving a water-space of a few inches between it and the shell; the whole was made water-tight by suitable packing in the rings. Water-pressure was then applied, and the deflection and crippling pressures were noted. This apparatus was designed to facilitate the removal of one flue after being tested, and the insertion of another. At first it would appear that this was a legitimate comparative test, and that both flues had been tested under exactly similar conditions; but upon consideration it would be found that the conditions were strongly in favour of the corrugated flue, and most unfavourable to the plain tube. Mr. Webster did not wish to underrate the value of the corrugated flues, for they had been proved to be undoubtedly strong. He was, however, of opinion that the published results of the comparative strengths of the two flues needed confirmation, and that the conditions of test were not identical. In the first place, the effective diameter of the two tubes was not the same. That both tubes might enter the testing apparatus, it was necessary for them to have exactly the same external maximum diameter, therefore the effective diameter of the corrugated flue was less than that of the plain flue by the depth of the corrugation, or say 2 inches, which would make a considerable difference in the crippling pressure. In the next place, the corrugated flue was in its strongest possible form, and was not dependent upon any system of rings or joints for increased strength, being entirely self contained, but the plain tube was in its weakest form. No one would fix a tube 8 feet long, and more than 3 feet in diameter, into any boiler working at a moderate pressure without stiffening rings, therefore on this ground, for the test to have been a fair one, the plain tube should have had the usual stiffening rings, one or two according to the pressure. Again, the tested tubes were not fixed at the ends, to enable them to be removed and replaced more easily; and this would affect the strength of the flues in about the same proportion as the relative strengths of a column when fixed or rounded at the ends. It might be urged that this objection could not hold, as both flues were under this condition; but it was probable, from the peculiar yielding nature of the corrugated tubes longitudinally, the fact of fixing the ends would afford little if any assistance, and it certainly could not give them the same support as it would to the

Mr. Webster. plain tubes. Taking all these points into consideration, he was of opinion that if a circular plain tube properly stiffened, fixed at the ends, and of the same diameter as the mean diameter of a corrugated tube were tested, the crippling strain would approach much nearer to that of the corrugated flue than the results quoted in the Paper.

The greater heating surface which the corrugated flues no doubt possessed could not be of much value, for the effective heating surface was hardly increased, the useful effect varying with the angle of the plate; and the greater expansion of the corrugated flue when heated must be rather a dangerous feature, notwithstanding the proposed additional longitudinal stays. As an illustration of the pitting and grooving of plates being due to the nature of the water, he gave an instance which occurred in his own experience. Two sets of boilers, of four in each set, were made at the same time about five years ago from the same design, and by a good maker; one set was worked with water pumped from the dock, and the other was worked with water supplied from the town mains. The latter boilers were still in good condition, but the former had given trouble about twelve months after they were started.

Mr. Smart. Mr. D. S. SMART, in reply upon the correspondence, remarked that the statement on p. 109 of the Paper appeared to have been misread. It was not there stated that calking or fullering had been given up by some makers, but only that they did not consider it necessary to calk or fuller the seams on the inside of a boiler.

Exception had been taken by Mr. Hayes to the dishing or expanding of the fire-box of the vertical boiler, shown by Fig. 10, round the bottom and at the furnace door. If the method preferred by Mr. Hayes had been shown, it would scarcely have represented "The Modern Practice in the Construction of Steam-Boilers." The insertion of a solid ring round the bottom of the fire-box of this type of boilers, though once the common practice, was now almost unknown. As it was a more expensive method than dishing, and had no real advantage over it, the change was not to be regretted. It might be said in favour of dishing that the rivets required were shorter and more easily made to fill the holes, and there was only one joint to be kept tight instead of two joints. The advantage of dishing at the furnace door was very evident. Under the old arrangement with the solid ring, the great thickness of metal round the opening was a constant source of trouble, through the fracturing of the furnace-plate at the edges owing to the overheating and the sudden contractions on opening the door. The dishing removed the joint somewhat out of the direct impact of the flame; and it would be observed from the sketch that a thinner ring was still inserted to reserve a water-space, and this also prevented stress upon the plate from further dishing, although a good quality either of iron or mild steel would sustain without injury considerably greater punishment than was required in this operation. The dished plate at the furnace door had the further advantage of permitting a fire-door frame to be inserted, when thought necessary, with provision on the fire-box side for retaining a fire-clay covering over the joint. Mr. Smart.

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10 February, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The discussion upon the Paper on "The Modern Practice in the Construction of Steam-Boilers," by Mr. D. S. Smart, occupied the whole evening.
