

The cost per lineal foot at £17 per ton was—

	£.
In the 120 feet span . . . .	28
„ 112 „ . . . .	25
„ 70 „ . . . .	17

The lattice was, in many cases, a convenient and economical mode of connecting the top and the bottom ribs of a girder; the simplest and cheapest application of the principle was, when the platform could be placed on the girder; it was also less subject to casualty, than when the platform was placed at some distance up the sides.

Mr. BRUNEL, V.P., said, that in considering this question, it was necessary to draw a distinct line of demarcation between the lattice bridge and that kind of construction called Warren's girder; in the former much of the material employed was useless, whilst in the latter, if properly proportioned, every part was made to perform its duty, either bearing pressure, or in tension; he was inclined to think it might be rendered nearly the most economical, as well as the most efficient kind of girder, for spans of a certain extent.

Mr. RENDEL, V.P., said, that Mr. C. H. Wild had recently investigated carefully, for him, the proportions and scantlings of some bridges on Warren's principle, intended to carry the lines of railway in India; for which locality their simplicity of construction, being composed of multiples of a few parts, the ease with which they could be transported to their destination, and the facility of putting them together, peculiarly fitted them. They were also cheap; a bridge of a span of 220 feet would cost about 15 per cent. less, than a lattice bridge for the same span. It was necessary not to confound the two principles, as the Warren girder was decidedly superior to the lattice bridge.

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November 18, 1851.

SIR WILLIAM CUBITT, President, in the Chair.

No. 860. "Description of a new metallic Manometer, and other instruments for measuring pressures and temperatures." By EUGENE BOURDON (Paris).

THE Author's attention has been for several years directed to the subject of pressure gauges and similar instruments, with the view of obtaining a more simple and perfect, as well as a more convenient instrument, than those hitherto employed, and having, as he believes, succeeded in obtaining this object, he desires to place the results of

his researches before the Institution of Civil Engineers, with the object of eliciting the general expression of opinion relative to the principle.

The instruments in ordinary use, for ascertaining the pressure of the atmosphere, and for measuring the pressure of steam and other fluids, may be divided into three principal classes.

In the first class, the pressure is ascertained by measuring the height of the column of mercury which it is capable of sustaining, as in the common barometer, and the ordinary mercurial pressure gauge.

In the second, the pressure of the air, or other fluid, is ascertained by the amount of compression it is capable of producing, in a portion of air confined in a bent tube, or syphon, by a portion of mercury, or other liquid. The sympisometer and the short mercurial steam gauge are constructed on this principle.

The third class consists of a cylinder, in which a piston moves, being at the same time attached to a spring; Watt's indicator is so constructed, and it has also been proposed to employ it as a barometer, by exhausting the air from the interior.

The difficulty of obtaining an air-tight piston, sufficiently free from friction, appears to have led M. Conté, at the latter end of the last century, to propose the application of a shallow air-tight box, covered with a thin metallic diaphragm, from beneath which the air was exhausted. The diaphragm was supported by springs, contained within the box, so that the thin metallic diaphragm rose, or fell, with any variation in the pressure of the atmosphere.

The instrument known as the aneroid barometer,\* is constructed in a somewhat similar manner, and the small motion of the diaphragm is multiplied by means of levers. A similar instrument was constructed by the Author in the year 1843, under the following circumstances. Having seen, in the French Exposition, a carriage, the springs of which were composed of thin lens-shaped metallic boxes, filled with compressed air, it occurred to him that a pressure gauge might be constructed on that principle; but on trying a series of experiments, by connecting the instrument with a steam boiler, it was found, that although at first it appeared to answer the purpose, yet after being used for a few weeks, or months, the metal cracked and the instrument became useless.

Sometime afterwards, the Author had occasion to construct a worm-pipe for a still, by bending a cylindrical tube into a spiral, or helical form. The workman performed the operation awkwardly,

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\* *Vide* Dent's Pamphlet descriptive of the Aneroid Barometer, page 15.

and partially flattened a considerable portion of the tube. In order to restore its form, one end was closed and the other was connected with a force pump, by which water was forced into the tube; as the flattened portion of the tube resumed its cylindrical form, it was observed that the spiral uncoiled itself to a certain extent, and it was immediately perceived that this action might be applied to the construction of a pressure gauge. Further experiments demonstrated the applicability of the principle to numerous uses, and the several forms of instruments shown in Plate 1, have been the result of subsequent experience.

Fig. 1 is a front view (showing also the sectional form) of a flattened metallic tube, bent into a circular form, and Fig. 2 is the side view. If a pressure of steam, or other fluid, be applied to the interior of this tube, it will be found to uncoil itself, as the pressure increases, until it assumes the form shown in Fig. 3, and on removing the pressure, it will return to its original form. If it is exposed to external pressure, or if the air is withdrawn from the interior, the tube coils itself up to a smaller diameter, as shown in Fig. 4. It will be found, that as the tube uncoils itself, it becomes thicker, from the sides becoming more convex, and as it coils itself up it becomes thinner. It is upon this relation, between the thickness of the tube and the diameter of the coil, that the action of the instrument depends.

If a flat band of metal is bent round into a circle, its transverse form remains unaltered, but if a semi-cylindrical, or gutter-shaped band, Fig. 5, is bent into a circular form, its convexity is diminished, and if the circle, to which it is bent, is of small diameter, the band will become almost flat in the transverse direction.

The same effect takes place, with a complete tube, as with the gutter-shaped band, and it is owing to this peculiarity, that tubular bodies possess such great rigidity. In fact, it is a law of general application, that a surface which is curved in two directions, cannot have its curvature increased in one direction, without diminishing its curvature in the other direction, and *vice versâ*. A tube may be considered as an assemblage of separate parallel filaments, or wires, as shown in Fig. 6. If such an assemblage of wires be bent into a curve, it will assume the form shown in Fig. 7, and the ends will no longer be square to the tube, as in Fig. 8, but will form angles to the radii of curvature, as in Fig. 9. The different parts of a tube, however, are not capable of sliding upon one another, like an assemblage of wires, but on the contrary, so mutually support each other, as to resist any attempt to bend the tube. If a curved gutter-shaped assemblage of wires is flattened out, it becomes round, or

convex at the ends, as in Fig. 10, from the central wires being longer than those at the sides, owing to their having originally formed a portion of a larger circle. If, on the other hand, the gutter be curved to a smaller diameter, the ends will become hollow instead of round. As these effects cannot take place in a gutter-shaped band, formed of one piece of metal, it becomes necessary for the different parts to accommodate themselves, in some other manner, to the varying curvature. This is effected by the change in the thickness of the tube, which allows the two sides to assume a greater degree of convexity in the transverse direction, in proportion to the diminution of their curvature in the longitudinal direction.

The converse of this proposition, equally holds good, that is to say, if pressure is applied to the interior of a curved tube of a flattened section, the effect is to separate the two sides of the tube, and thus to increase their convexity in the transverse direction. The consequence is the diminution of their curvature in the longitudinal direction.

From these considerations it follows, that a curved tube of cylindrical, or circular section, will not experience any change of curvature, when submitted to internal pressure, as the circle is the sectional form which all tubes tend to assume, when exposed to internal pressure. As the sectional form, therefore, cannot alter, the longitudinal curvature ought also to remain unchanged.

This theoretical observation is confirmed by actual experiment, the curved tube of circular section remaining unaltered in form, when submitted to internal pressure. The result is the same with external pressure, provided, of course, that the pressure is insufficient to totally collapse and destroy the tube.

The mutual dependence of the two curvatures on each other, is also proved in the following manner. When the flattened tube is embraced by a series of small clamps, as shown in Fig. 13, so as to prevent its sectional form from altering, on the application of internal pressure, its longitudinal curvature also remains unchanged.

Also, when the two ends of the tube are joined, so as to complete the circle, and pressure is applied, the tube, being unable to alter its longitudinal curvature, remains unaltered in thickness.

The variation in the thickness of a curved flattened tube, with the variations of its curvature, may be proved, by actual measurement, to be proportional to the change in its curvature, and *vice versa*; it may also be well shown by filling the tube with a liquid, and attaching a small glass cylinder to it, when every change of

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curvature causes a corresponding motion in the liquid in the cylinder; the capacity of the tube increasing as it is straightened, and diminishing as it is coiled up.

Again, if the external side of the tube be an arc of a radius of 60 parts, and the internal side be an arc of a radius of 50 parts, the thickness, or capacity of the tube would be 10 parts. If the thickness of the tube were then reduced to 8 parts, by approaching the two arcs together, without altering their curvatures, the external arc would necessarily be too long, and the internal arc too short, for their new positions, and the ends of the tube would be out of square, or be distorted. As, however, the metal resists this distortion, the tube accommodates itself to its new position, by increasing its curvature, so that the radii of the external and the internal arcs may still retain their former relative proportions. They therefore become 48 parts, and 40 parts respectively, and the arc of curvature is increased in the proportion of 4 to 5, whilst the thickness, or capacity of the tube is reduced in the proportion of 5 to 4. Thus, if the tube formed originally an arc of  $60^\circ$ , it will now form an arc of  $75^\circ$ .

The change in thickness of the tube, is thus proportional to the variation of its radius of curvature, and it is found, by experiment, that the motion of the extremities of the tube is proportional to the pressure applied, so that the indications are equal for equal increments of pressure.

This fact is of great practical importance, as the application of the principle to the construction of Pressure-Gauges, Barometers, and other instruments, is thereby greatly facilitated.

The simplest of these instruments, is the Steam-Pressure Gauge, Figs. 14, 15, and 16, in which rather more than one convolution of flattened tube, *A*, is employed; one end of this tube is fixed to a stop-cock, *C*, in connection with the steam boiler, by the pipe, *B*, and the other end carries an index point, *d*, the extremity of which traverses a scale, *E*, graduated to a given pressure per square inch. In some cases there is a small slider, or an additional loose hand, *e*, which being pushed forward by the motion of the index, serves to register the maximum, or minimum pressure. Figs. 17 and 18 represent another form of Pressure Gauge, in which the tube, *A*, makes one turn, and is connected by a link, *e*, to the index, *d*.

These instruments answer perfectly for fixed engines, but if their position is varied, by laying them on their sides, the weight of the tube causes it to spring, and thus to interfere with the accuracy of the indications. In cases, therefore, in which the position of the instrument is exposed to variation, as in sea-going vessels, it is preferable to employ a circular tube fixed in the centre, to the stop-

cock, and having its ends connected by links, to the two ends of a lever turning upon a centre and carrying the index. The two branches of the tube are thus made to balance each other, and the index being also balanced, the instrument may be placed in any position, without its indications being in any degree affected. Figs. 19, 20, and 21, represent an instrument thus constructed and furnished with an illuminated scale, or dial.

When a great range of motion is required, the lever, instead of being placed on the axis of the index, carries a toothed segment, which drives a pinion on the spindle of the index, thus increasing the extent of indication. This arrangement, which is shown in Fig. 22, is well adapted for Barometers, in the construction of which, the air is exhausted from the flattened tube, before it is soldered up. The pressure of the atmosphere acts on the exterior, and is balanced by the elasticity of the tube, which varies in curvature, with every variation in the pressure of the atmosphere.

The manometers, above described, may be used as Vacuum Gauges, by continuing the scale below zero.

In some cases, and especially where the Manometers are liable to be exposed to frost, it is advisable to prevent the entrance of water into the flattened tube; this is effected, by interposing, in the pipe which leads to it, a flat box containing a diaphragm of vulcanized India-rubber. The flattened tube, and the space between it and the diaphragm, are filled with alcohol, or other liquid not liable to be congealed by cold, and the flattened tube is thus protected from injury. This arrangement is shown in Fig. 23.

If the curved flattened tube be filled with alcohol, or other liquid, and hermetically closed, the instrument becomes a Thermometer, showing by the motion of the index, every change in the volume of the inclosed liquid. The tube being formed of metal, has the advantage of transmitting the heat to the inclosed liquid, with greater rapidity than is the case with a glass thermometer. In some cases, however, as in ascertaining the temperature of corrosive liquids, it might be advisable to employ a tube of glass.

A Pyrometer, for measuring high temperatures, is made by connecting one of the pressure gauges by a small platinum tube, to a hollow ball of platinum filled with air. The platinum ball being exposed to heat, the elasticity of the air contained in it is increased, and the pressure is indicated by the gauge.

If instead of bending the flattened tube, it is twisted, by fixing one end and turning the other round, a sort of quick threaded screw is obtained, which has the property of untwisting itself, when acted on by internal pressure, and *vice versâ*. The action of the twisted

tube depends upon the same law, which has already been enunciated, namely, that a surface which is curved in two directions, cannot have its curvature increased in one direction, without diminishing its curvature in the other direction.

In fact, if any portion of the surface of the twisted tube be examined, it will be found to be curved in two directions, but instead of the two curvatures being at right angles to one another, they form an angle more, or less acute. Figs. 24 and 25 represent an instrument of this construction.

The motion of the twisted tube is indicated by a hand fixed to its extremity, or the motion is increased by means of gearing, or levers.

A thermometer made by filling one of these twisted tubes with alcohol, or other liquid, and provided with a float, is convenient for enabling brewers and others to ascertain the temperature of large quantities of liquid. The thermometer is allowed to float in the liquid, and the temperature can be read from the dial, without the necessity of lifting the instrument out of the liquid.

It would be tedious to mention all the modifications of which these instruments are susceptible; a few, however, may be alluded to as illustrating the others.

By employing a tube of suitable dimensions, in connection with a steam boiler, it may be made to open and shut the damper, and thus to regulate the pressure in the boiler. By a similar arrangement, a thermometer may be made to regulate an Arnott's stove, or a furnace.

In the steam-engine Indicators on this principle, Figs. 26, 27, and 28, a bent and flattened tube is substituted for the cylinder, piston, and spring of the ordinary indicator. One end of the bent tube is connected with the cylinder of the steam engine by a pipe, *B*, and the other end of the tube is attached by a short link to the middle of a long and light lever, *g g*, turning upon a pin, *f*, at its lower end. The pencil, *i*, is fixed to the upper end of the lever, and works across the paper, *H*, which is fixed on a vertical brass plate. This brass plate is moved up and down by means of a rack, *k*, and pinion, *l*. The pinion is driven by a pulley, *p*, fixed on its axis, and containing a flat circular box, in which is a spiral spring. A cord is fixed to, and wound several times round a pulley and is then attached to the cross-head, or to the beam, or parallel motion of the steam-engine; being always kept tight by the spiral spring. As the pencil moves in a small arc of a circle, whose radius is the long lever, it is necessary to measure the diagram with a scale of the same curvature. This instrument is extremely simple, and very effective.

Fig. 1.



Fig. 2.

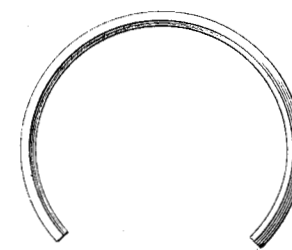


Fig. 3.

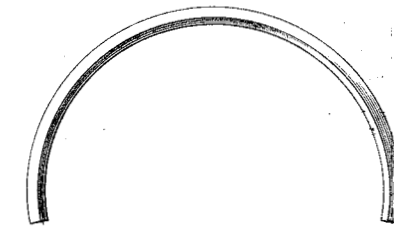


Fig. 4.

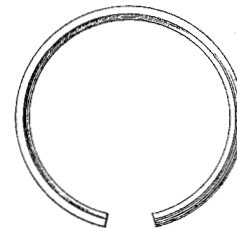


Fig. 5.



Fig. 6.

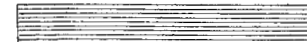


Fig. 7.

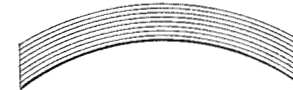


Fig. 8.

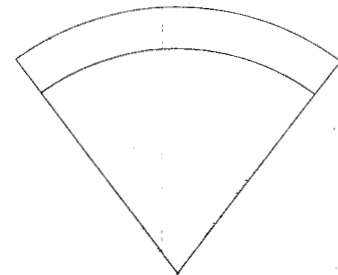


Fig. 9.

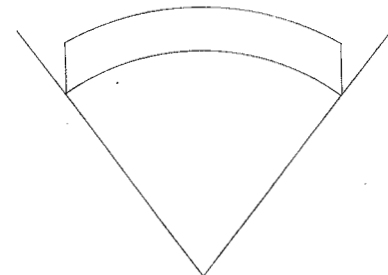


Fig. 10.

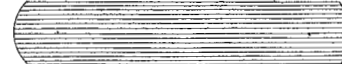


Fig. 24.

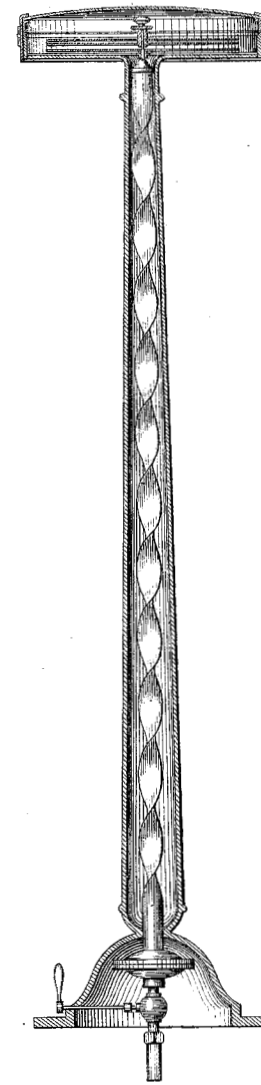


Fig. 11.



Fig. 12.

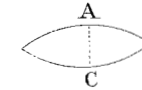


Fig. 13.



Fig. 14.

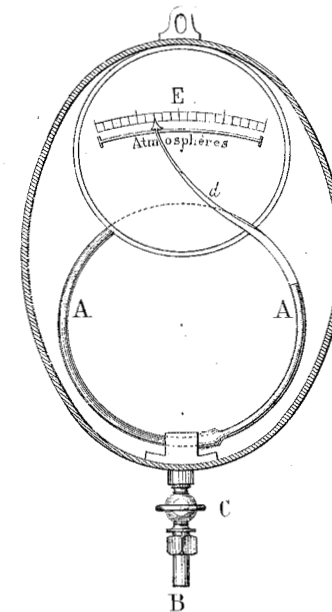


Fig. 15.

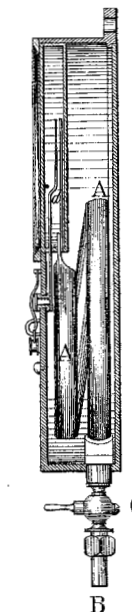


Fig. 16.

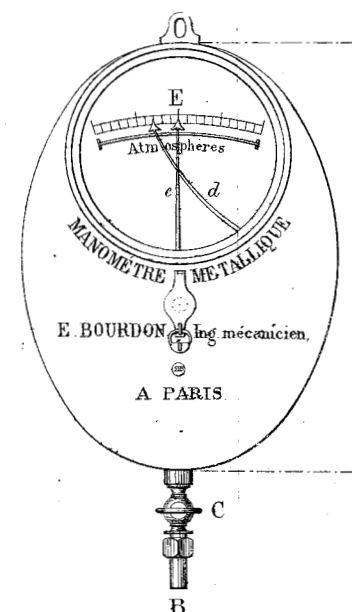


Fig. 17.

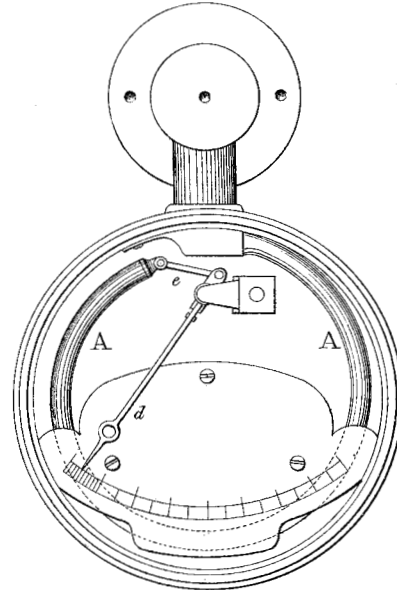


Fig. 18.

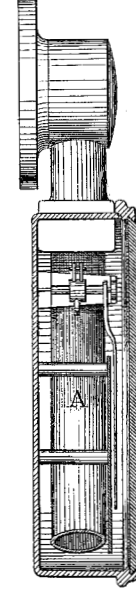


Fig. 19.

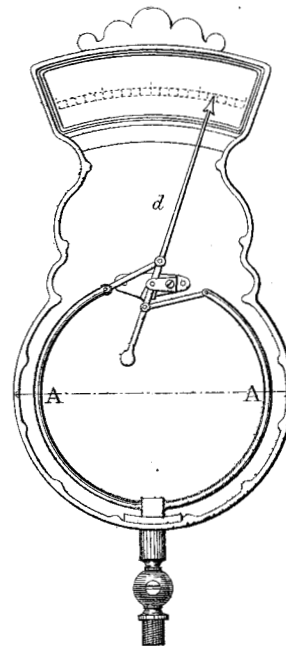


Fig. 20.

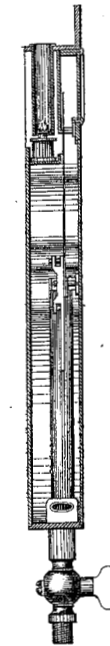


Fig. 21.

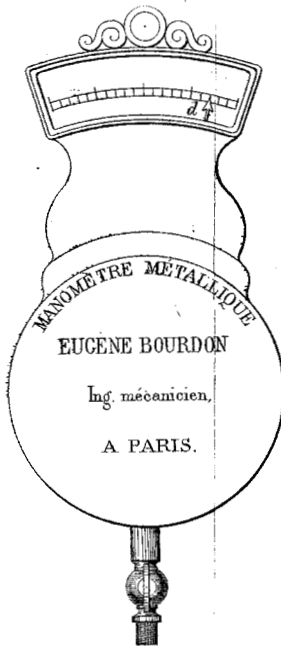


Fig. 22.

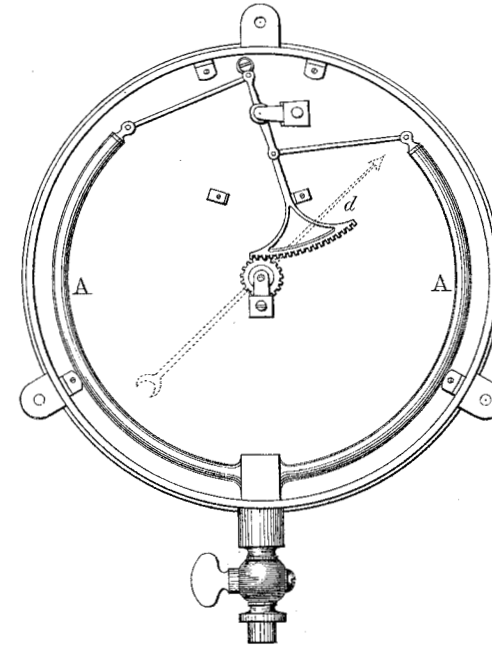


Fig. 23.

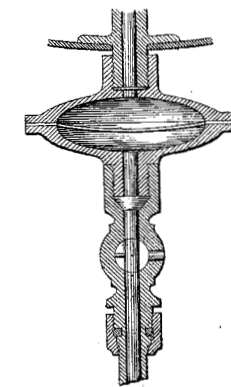


Fig. 25.

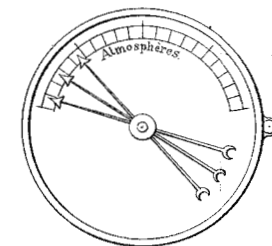


Fig. 26.

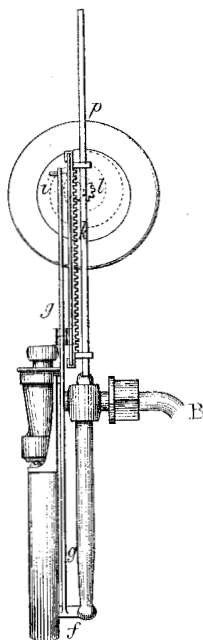


Fig. 28.

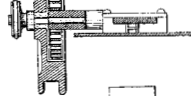
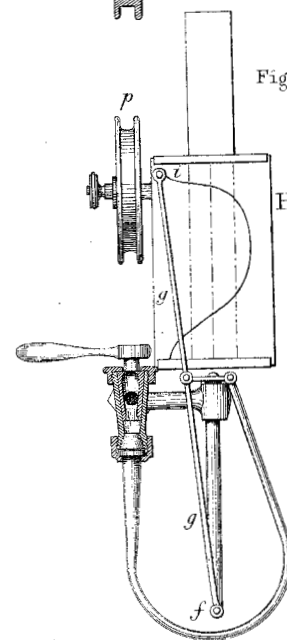


Fig. 27.





The Author has also constructed a small experimental steam-engine, in which a bent and flattened steel tube is substituted for the ordinary piston and cylinder. One end of the bent tube is fixed to the framing, and provided with a slide valve; the other end of the tube is connected by a rod to the crank, and is supported by a lever, of such proportions as to agree in its motion with that of the free end of the bent tube. The slide valve is worked by an eccentric on the crank shaft. The bent tube is filled with oil, or water, so that the steam only enters the fixed vertical part of the tube, to an extent equal to the difference in the capacities of the tube in different positions. The loss of steam in filling the whole of the tube at each stroke is thus avoided. This engine has been driven at a very high velocity, without injury, which appears to be owing to the elasticity of the tube, forming a sort of cushion at each end of the stroke, and thus assisting in reversing the motion. This form of engine could not be expected to be generally adopted, in fact it was rather intended as an exemplification of the principle, than as a machine for common use; where, however, a small power, at a high velocity, is required, its freedom from friction might perhaps recommend it.

After many years' patient investigation of the subject, the Author has had the satisfaction of finding the correctness of the principle generally admitted, and his labours have been rewarded by a Gold Medal, at the French Exposition of 1849; and also by the Council Medal, at the Great Exhibition, in Hyde Park, in 1851. The French Government, upon the report of a special Commission, appointed to examine the instruments, has recently ordered, that one of the Pressure Gauges shall be provided for each of the Departmental Engineers engaged in the inspection of steam-engines, for the purpose of enabling them to verify the accuracy of all other descriptions of manometers, or pressure gauges, employed in Manufactories, or on Locomotive Engines, and on board Steam Vessels. These pressure gauges are also directed to be employed, according to the law, in proving boilers, by hydraulic pressure, equal to three times their ordinary working pressure, and for this purpose the French Government has ordered the Author to furnish a hundred standard manometers.

The principle developed in these instruments is brought forward with confidence in its correctness, and in the hope that the attention of the Members of the Institution being directed to the subject, further applications of practical utility may be devised.

The paper is illustrated by a series of diagrams, showing the various applications of the principle, and from them Plate 1 has been compiled.

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