

ON BOURDON'S METALLIC BAROMETER, INDICATOR,
AND
OTHER APPLICATIONS OF THE SAME PRINCIPLE.

Various instruments have been invented and employed for Measuring the Pressure of the Atmosphere, and also for Measuring the Pressure of Steam and other Fluids, but they may be divided into three principal classes.

In the first of these, 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 class, the pressure of the air or other fluid is ascertained by the amount of compression which 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 Sympiesometer and the Short Mercurial Steam Gauge are constructed on this principle.

The third class consists of a cylinder and piston, the piston being attached to a spring; Watt's Indicator is constructed on this principle, 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, and exhausted of air. The diaphragm was supported by springs contained within the box, so that it rose and fell with the variations in the pressure of the atmosphere. The instrument known as the Aneroid Barometer is constructed in a similar manner, and the small motion of the diaphragm is greatly multiplied by means of levers. A similar instrument was constructed by M. Bourdon, as long since as the year 1843, for the purpose of a steam gauge. After many experiments, however, he laid it aside, as he found that the metal cracked after a continued use, and rendered the instrument useless.

The invention of the Instruments which are the subject of the present Paper, was the result of a careful observation of an accidental circumstance. M. Bourdon had occasion to restore the form of a worm-pipe of a still, which had been accidentally flattened. To effect this, he closed one end and forced water in it at the other end. The flattened tube expanded to its proper form, but at the same time M. Bourdon observed that the tube uncoiled itself to a certain extent, and it occurred to him to apply this fact to the construction of a Pressure-gauge. He did so, and with perfect success.

The principle of the Instruments will be best explained with the aid of the accompanying diagrams, Plate 65.

Fig. 1 is a section, and Fig. 2 a front view of a flattened metallic tube, bent into a circular form. 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, like that shown at A, in Fig. 5, is bent into a circular form, its convexity is diminished, as shown at B, 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 versa*.

A tube may be considered as an assemblage of separate parallel filaments or wires, and if a curved gutter-shaped assemblage of wires, as shown in Fig. 6, is flattened out, it assumes the form shown in plan in Fig. 7, 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 to the varying curvature in some other manner. 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 B of a flattened section similar to that shown in Fig. 8, the effect is to separate the two sides of the tube in the direction of the line AC, and thus to increase their convexity in the transverse direction, as shown at D. The consequence is the diminution of their curvature in the longitudinal direction, as shown at E.

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 dependance of the two curvatures on one another is also proved in the following manner. When the flattened tube is embraced by a series of separate small clamps, of the form shown in Fig. 9, so as to prevent its sectional form from altering on the application of internal pressure, the consequence is that its longitudinal curvature also remains unchanged.

On the other hand, when the two ends of the tube are joined so so as to complete the circle, and the pressure is then applied, the consequence is that the tube, being unable to alter its longitudinal curvature, remains also unaltered in thickness.

The variation in the thickness of a curved flattened tube with variations of curvature is proved by actual measurement.

This variation is proportional to the change in its curvature, and *vice versa*. Thus, in Fig. 10, ABCD represents a curved

flattened tube, the arc AB having a radius of 60 parts, and the arc CD having a radius of 50 parts, the interval AC or the thickness of the tube being 10. If the arc AB is brought closer to CD by the application of external pressure, the arc AB will necessarily be too long for its new position. To establish the proper relation between the two arcs, their respective radii must still maintain their original relative proportion, or in other words, if the distance AC is reduced to eight parts or diminished one fifth, the radii must also be diminished one fifth each, and reduced to forty-eight and forty parts respectively. The length of the arc remaining constant, while the diameter is reduced, the radii will necessarily form an angle one fourth larger than in the original position, that is to say, if the original angle was sixty degrees, it will now be increased to seventy-five degrees. In Fig. 11 the dark lines show the original form, and the dotted lines show the effect produced by approaching the two arcs together. Fig. 12 shows the new form acquired by the tube.

The change in thickness of the tube is thus proportioned 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 considerable importance, as it greatly facilitates the application of the principle to the construction of pressure-gauges, barometers, and other instruments.

The simplest form of these instruments is the Steam Pressure-gauge, Figs. 16 and 17, Plate 66, in which rather more than one convolution of flattened tube AA is employed. One end of this tube is fixed to a stop-cock B, in connection with the steam boiler, and the other end carries an index C, the extremity of which traverses over a scale graduated to pounds pressure per square inch. In some cases a small slider or an additional loose hand is added, which is pushed forward by the motion of the index, and serves to register the maximum or minimum pressure.

In another form of the instrument, the flattened tube is fixed at the top, and makes one turn, and the free end is connected by

G

a link to a lever and index. These instruments serve equally well as pressure-gauges and as vacuum-gauges. The dimensions of the tube and scale are varied according to the pressure to which they are to be exposed, and the degree of delicacy required in the indications.

This instrument answers perfectly for fixed engines, but if its position is varied by laying it on its side, the weight of the tube causes it to spring a little, and thus to interfere with the accuracy of its indications. Therefore, in cases in which the position of the instrument is exposed to variation, as in seagoing 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 thereby affected.

When a great range of motion is required, the lever is not placed on the axis of the index, but carries a toothed segment which drives a pinion on the spindle of the index.

Figs. 18 and 19 show a Pressure-gauge constructed in this manner. The bent tube AA is fixed in the centre, and the two branches of the tube are made to balance each other. The lever B to which they are connected gives motion to a toothed sector C, which is also balanced, and which drives a pinion on the axis of the index D, which is balanced.

This arrangement is well adapted for Barometers, in which case the air is exhausted from the flattened tube, which is then 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. In order to prevent any slackness in the different joints from affecting the accuracy of the indication, a small hair-spring may be attached to the axis of the index, which will keep a slight tension upon all the joints, and keep the teeth of the pinion always in gear with the same side of the teeth of the sector. The Barometers are constructed with broader and thinner tubes than the steam pressure-gauges, as the variations of pressure to which they are subjected

being comparatively small, it is desirable to obtain a considerable motion with these small variations of pressure.

Fig. 13, Plate 65, is the section of tube which is generally employed for Barometers, while Figs. 14 and 15 are generally employed for steam pressure-gauges.

In order to give some idea of the extent of motion which is readily obtainable in these instruments, the following experiment may be mentioned. A tube of the sectional form shown in Fig. 13, and about three inches wide, was bent into a circle of about ten inches diameter. One end of the tube was closed, and a small tube attached to the other extremity. By placing this tube to the mouth, and blowing into the tube, it was caused to expand, and by sucking out the air the tube was made to contract. The motion thus produced in the free end of the tube was fully three inches. In the Barometers in which a tube about one inch wide is bent into a circle of about four inches diameter, the motion caused by exhausting the air from the tube is about an inch, but varies according to the sectional form and thickness of the metal which forms the tube.

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 enclosed liquid. The tube, being formed of metal, has the advantage of transmitting the heat to the enclosed 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 temperature, 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 its pressure is indicated by the pressure-gauge.

If in place 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 versa*. 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 in place of the two curvatures being at right angles to one another, they form an angle more or less acute. 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, as shown in Figs. 20 and 21, 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 is read off on the dial, without the necessity of lifting the instrument out of the liquid.

All the applications of which these instruments are susceptible need not be mentioned; a few, however, may be alluded to, as illustrating the others.

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

A steam-engine Indicator is made by removing the cylinder piston and spring of an ordinary Indicator, and substituting a bent or twisted tube. Fig. 22 is a front view, partly in section, and Fig. 23 is a side view of such an Indicator. The bent tube A is placed at the lower part, and connected by a short link to a long lever, which carries the pencil B at its upper end. The paper or card is fixed on a brass plate C, which slides up and down on a fixed guide, and is moved by a pinion working into a rack on the back of the plate. This pinion carries a pulley D upon its axis, which is driven by a string from the beam or parallel motion of the engine. This pulley can be removed, and replaced by others of different diameters; this gives great facility in the application of the Indicator to different engines, especially to direct-acting

engines, where the motion may be taken at once from the cross-head by employing a large pulley. The pulley and pinion are mounted on a spindle passing through a fixed hollow pin. A spiral spring is attached to the fixed pin, and enclosed in a flat circular box, which fits in a cavity in the side of the pulley; this spring serves to keep the string always in a state of tension.

The long lever which carries the pencil turns on a fixed pin at bottom, and prevents the pencil from being moved out of its course by the friction of the paper against it, which might happen if the pencil were attached at once to the tube. The ends of the figure drawn on the paper are slightly curved, and it is necessary to measure the figure with a curved scale of the same radius as the lever.

To show that the principle may be carried out on a still larger scale, M. Bourdon has constructed a single-acting Steam Engine, in which a curved flattened tube made of two steel plates is employed in place of the cylinder and piston. This engine is shown in Fig. 24. One end of the tube A is fixed, and the other is united by a connecting-rod to a crank B, and fly-wheel. A slide valve C, is attached to the fixed end of the tube, and worked by an eccentric D, on the crank shaft. The steam is thus alternately admitted and discharged from the tube, and the engine has thus been worked at a speed of several hundred strokes per minute. To avoid unnecessary loss of steam, the tube is filled with oil, so that the steam only enters a portion of the tube, equal to the increase of its capacity produced by the pressure of the steam. The moving end of the tube A is guided by the lever E, which is adjusted to move in the natural path of the end of the tube without causing any strain. The crank B is slotted with a moveable crank pin for varying the length of stroke, according to the pressure and the corresponding extent of motion of the tube. When the engine is non-condensing, the crank is set a little past the centre when the engine is at rest, but when the engine is condensing, it is set near half-stroke when at rest, as the tube expands with the steam-pressure, and collapses with the vacuum. The piston friction is avoided in this engine, and it may therefore be found economical for small engines.

In all cases in which accuracy of indications is required in the pressure-gauges, it is advisable to prevent the steam from entering the bent tube, whose elasticity would be reduced as long as it remained in a heated state. This is readily effected by causing the pipe which connects the gauge to the boiler or engine to *descend* to the gauge, as shown at E in Fig. 16: it will then always remain full of condensed water, and the gauge tube will be kept cool.

Mr. C. COWPER exhibited specimens of the different instruments and models, illustrating the principle of action. He said the steam gauges had come into extensive use in France, and he understood they were found very satisfactory and trustworthy; they were employed by the Government inspectors to test the pressure of steam boilers throughout that country.

Mr. BUCKLE observed that they appeared most useful gauges for general application, and well suited to many different purposes in practice.

Mr. PEACOCK said he had made trial of a pair of these steam gauges for the last eight months, on the boilers of a steam boat, working at 25 lbs. pressure, and he had found them quite satisfactory; they had not gone wrong at all during the time, nor had the index taken any permanent set.

Mr. C. COWPER remarked that the application of the principle to a steam engine had not been carried out on a large scale; an engine of about half a horse power had been made to show the application, and had been sent to the Exhibition. The different instruments could be inspected afterwards and obtained at Mr. Dewrance's office in London.

A vote of thanks was passed to Mr. Cowper for his communication, and the meeting then terminated.

[Mr. McConnell having been obliged to leave before the termination of the meeting, the Chair was then taken by Mr. Buckle.]

BOURDON'S GAUGES.

Plate 65.

Diagrams, illustrating the principle of Action.

Fig. 1.

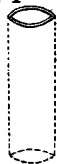


Fig. 2.

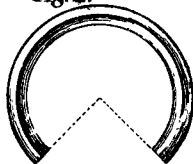


Fig. 3.



Fig. 4.

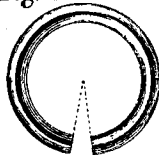


Fig. 5.

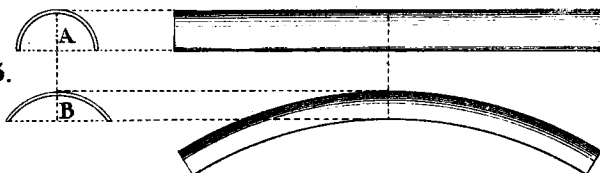


Fig. 6.



Fig. 7.



Fig. 8.

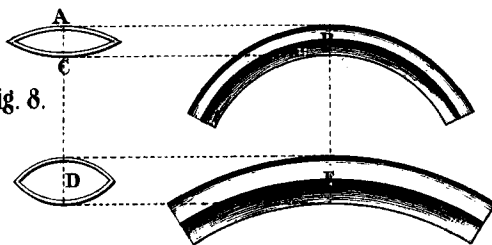


Fig. 9.

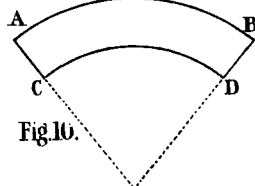


Fig. 10.

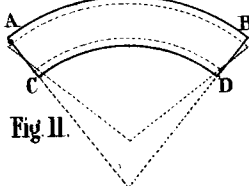


Fig. 11.

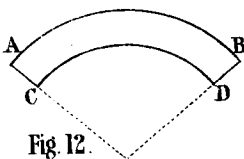


Fig. 12.

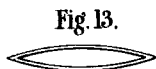


Fig. 13.

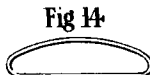


Fig. 14.



Fig. 15.

BOURDON'S GAUGES.

Steam Pressure Gauge

Fig. 16.

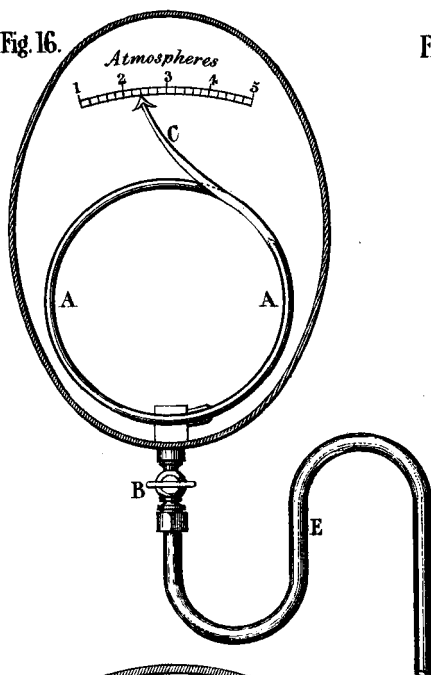


Fig. 17.



Fig. 18.

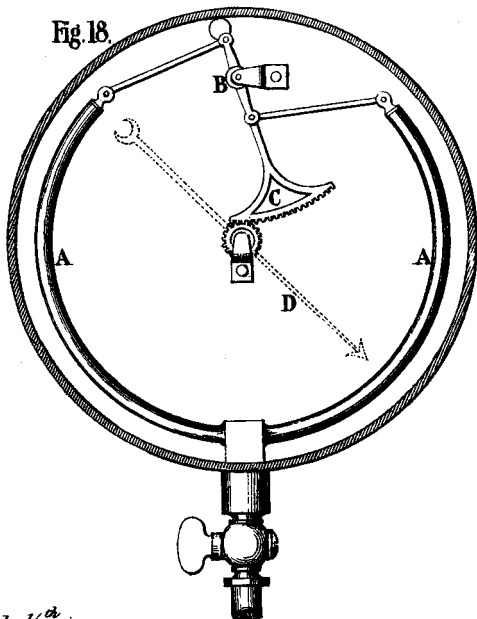


Fig. 19.

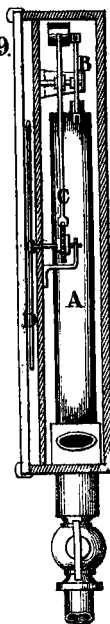
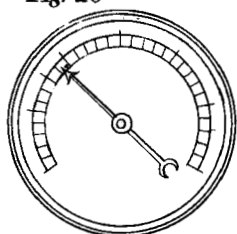


Fig. 20



Thermometer.



Fig. 21.

Fig. 23.

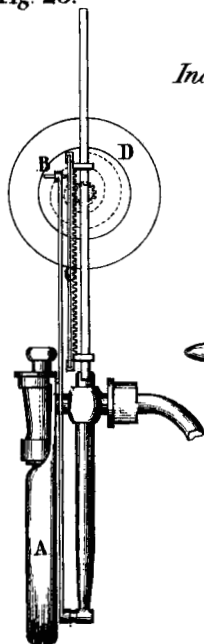
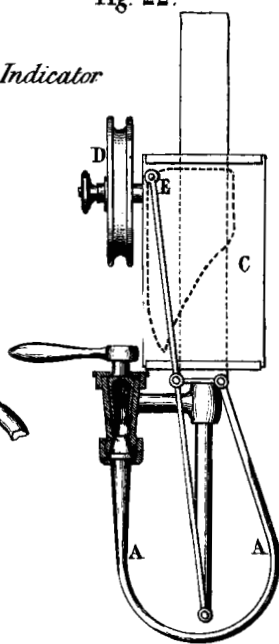


Fig. 22.

Indicator



Scale 1/4" size

Fig. 24

Steam Engine.

