MECHANICAL PRINCIPLES

OF

THE STEAM ENGINE.

CLASSIFICATION OF ENGINES.

1. *Q.*—What is meant by a vacuum?

A.—A vacuum means an empty space; a space in which there is neither water nor air, nor anything else that we know of.

2. *Q.*—Wherein does a high pressure differ from a low pressure engine?

A.—In a high pressure engine the steam, after having pushed the piston to the end of the stroke, escapes into the atmosphere, and the impelling force is therefore that due to the difference between the pressure of the steam and the pressure of the atmosphere. In the condensing engine the steam, after having pressed the piston to the end of the stroke, passes into the condenser, in which a vacuum is maintained, and the impelling force is that due to the difference between the pressure of the steam above the piston, and the pressure of the vacuum beneath it, which is nothing; or, in other words, you have then the whole pressure of the steam urging the piston, consisting of the pressure shown by the safety-valve on the boiler, and the pressure of the atmosphere besides.

3. *Q.*—In what way would you class the various kinds of condensing engines?

A.—Into single acting, rotative, and rotatory engines. Single acting engines are engines without a crank, such as are used for pumping water. Rotative engines are engines provided with a crank, by means of which a rotative motion is produced; and in this important class stand marine and mill engines, and all engines, indeed, in which the rectilinear motion of the piston is changed into a circular motion. In rotatory engines the steam acts at once in the production of circular motion, either upon a revolving piston or otherwise, but without the use of any intermediate mechanism, such as the crank, for deriving a circular from a rectilinear motion. Rotatory engines have not hitherto been very successful, so that only the single acting or pumping engine, and the double acting or rotative engine can be said to be in actual use. For some purposes, such, for example, as forcing air into furnaces for smelting iron, double acting engines are employed, which are nevertheless unfurnished with a crank; but engines of this kind are not sufficiently numerous to justify their classification as a distinct species, and, in general, those engines may be considered to be single acting, by which no rotatory motion is imparted.

4. *Q.*—Is not the circular motion derived from a cylinder engine very irregular, in consequence of the unequal leverage of the crank at the different parts of its revolution?

A.—No; rotative engines are generally provided with a fly-wheel to correct such irregularities by its momentum; but where two engines with their respective cranks set at right angles are employed, the irregularity of one engine corrects that of the other with sufficient exactitude for many purposes. In the case of marine and locomotive engines, a fly-wheel is not employed; but for cotton spinning, and other purposes requiring great regularity of motion, its use with common engines is indispensable, though it is not impossible to supersede the necessity by new contrivances.

5. *Q.*—You implied that there is some other difference between single acting and double acting engines, than that which lies in the use or exclusion of the crank?

A.—Yes; single acting engines act only in one way by the force of the steam, and are returned by a counter-weight; whereas double acting engines are urged by the steam in both directions. Engines, as I have already said, are sometimes made double acting, though unprovided with a crank; and there would be no difficulty in so arranging the valves of all ordinary pumping engines, as to admit of this action; for the pumps might be contrived to raise water both by the upward and downward stroke, as indeed in some mines is already done. But engines without a crank are almost always made single acting, perhaps from the effect of custom, as much as from any other reason, and are usually spoken of as such, though it is necessary to know that there are some deviations from the usual practice.

NATURE AND USES OF A VACUUM.

6. *Q.*—The pressure of a vacuum you have stated is nothing; but how can the pressure of a vacuum be said to be nothing, when a vacuum occasions a pressure of 15lbs. on the square inch?

A.—Because it is not the vacuum which exerts this pressure, but the atmosphere, which, like a head of water, presses on everything immerged beneath it. A head of water, however, would not press down a piston, if the water were admitted on both of its sides; for an equilibrium would then be established, just as in the case of a balance which retains its equilibrium when an equal weight is added to each scale; but take the weight out of one scale, or empty the water from one side of the piston, and motion or pressure is produced; and in like manner pressure is produced on a piston by admitting steam or air upon the one side, and withdrawing the steam or air from the other side. It is not, therefore, to a vacuum, but rather to the existence of an unbalanced plenum, that the pressure made manifest by exhaustion is due, and it is obvious therefore that a vacuum of itself would not work an engine.

7. *Q.*—How is the vacuum maintained in a condensing engine?

A.—The steam, after having performed its office in the cylinder, is permitted to pass into a vessel called the condenser, where a shower of cold water is discharged upon it. The steam is condensed by the cold water, and falls in the form of hot water to the bottom of the condenser. The water, which would else be accumulated in the condenser, is continually being pumped out by a pump worked by the engine. This pump is called the air pump, because it also discharges any air which may have entered with the water.

8. *Q.*—If a vacuum be an empty space, and there be water in the condenser, how can there be a vacuum there ?

A.—There is a vacuum above the water, the water being only like so much iron or lead lying at the bottom.

9. *Q.*—Is the vacuum in the condenser a perfect vacuum ?

A.—Not quite perfect; for the cold water entering for the purpose of condensation is heated by the steam, and emits a vapor of a tension represented by about three inches of mercury; that is, when the common barometer stands at 30 inches, a barometer with the space above the mercury communicating with the condenser, will stand at about 27 inches.

10. *Q.*—Is this imperfection of the vacuum wholly attributable to the vapor in the condenser ?

A.—No; it is partly attributable to the presence of a small quantity of air which enters with the water, and which would accumulate until it destroyed the vacuum altogether but for the action of the air pump, which expels it with the water, as already explained. All common water contains a certain quantity of air in solution, and this air recovers its elasticity when the pressure of the atmosphere is taken off, just as the gas in soda water flies up so soon as the cork of the bottle is withdrawn.

11. *Q.*—Is a barometer sometimes applied to the condensers of steam engines ?

A.—Yes; and it is called the vacuum gauge, because it shows the degree of perfection the vacuum has attained. Another gauge, called the steam gauge, is applied to the boiler, which indicates the pressure of the steam by the height to which the steam forces mercury up a tube. Gauges are also applied to the boiler to indicate the height of the water within it so that it may not be burned out by the water becoming accidentally too low. In some cases a succession of cocks placed a short distance above one another are employed for this purpose, and in other cases a glass tube is placed perpendicularly in the front of the boiler and communicating at each end with its interior. The water rises in this tube to the same height as in the boiler itself, and thus shows the actual water level. In most of the modern boilers both of these contrivances are adopted.

12. *Q.*—Can a condensing engine be worked with a pressure less than that of the atmosphere?

A.—Yes, if once it be started; but it will be a difficult thing to start an engine, if the pressure of the steam be not greater than that of the atmosphere. Before an engine can be started, it has to be blown through with steam to displace the air within it, and this cannot be effectually done if the pressure of the steam be very low. After the engine is started, however, the pressure in the boiler may be lowered, if the engine be lightly loaded, until there is a partial vacuum in the boiler. Such a practice, however, is not to be commended, as the gauge cocks become useless when there is a partial vacuum in the boiler; inasmuch as, when they are opened, the water will not rush out, but air will rush in. It is impossible, also, under such circumstances, to blow out any of the sediment collected within the boiler, which, in the case of the boilers of steam vessels, requires to be done every two hours or oftener. This is accomplished by opening a large cock which permits some of the supersalted water to be forced overboard by the pressure of the steam. In some cases, in which the boiler applied to an engine is of inadequate size, the pressure within the boiler will fall spontaneously to a point considerably beneath the pressure of the atmosphere; but it is preferable, in such cases, partially to close the throttle valve in the steam pipe, whereby the issue of steam to the engine is diminished; and the pressure in the boiler is thus maintained, while the cylinder receives its former supply.

13. *Q.*—If a hole be opened into a condenser of a steam engine, will air rush into it ?

A.—If the hole communicates with the atmosphere, the air will be drawn in.

14. *Q.*—With what velocity does air rush into a vacuum ?

A.—With the velocity which a body would acquire by falling from the height of a homogeneous atmosphere, which is an atmosphere of the same density throughout as at the earth's surface; and although such an atmosphere does not exist in nature, its existence is supposed, in order to facilitate the computation. It is well known that the velocity with which water issues from a cistern is the same that would be acquired by a body falling from the level of the head to the level of the issuing point; which indeed is an obvious law, since every particle of water descends and issues by virtue of its gravity, and is in its descent subject to the ordinary laws of falling bodies. Air rushing into a vacuum is only another example of the same general principle: the velocity of each particle will be that due to the height of the column of air which would produce the pressure sustained; and the weight of air being known, as well as the pressure it exerts on the earth's surface, it becomes easy to tell what height a column of air, an inch square, and of the atmospheric density, would require to be, to weigh 15lbs. The height would be 27,818 feet, and the velocity which the fall of a body from such a height produces would be 1,338 feet per second.

VELOCITY OF FALLING BODIES AND MOMENTUM OF MOVING BODIES.

15. *Q.*—How do you determine the velocity of falling bodies of different kinds ?

A.—All bodies fall with the same velocity, when there is no resistance from the atmosphere, as is shown by the experiment of letting fall, from the top of a tall exhausted receiver, a feather and a guinea, which reach the bottom at the same time. The velocity of falling bodies is one that is accelerated uniformly, according to a known law. When the height from which a body falls is given, the velocity acquired at the end of the descent can be easily computed. It has been found by experiment that the square root of the height in feet multiplied by 8·021 will give the velocity.

16. *Q.*—But the velocity in what terms?

A.—In feet per second. The distance through which a body falls by gravity in one second is $16\frac{1}{12}$ feet; in two seconds, $64\frac{4}{12}$ feet; in three seconds, $144\frac{9}{12}$ feet; in four seconds, $257\frac{4}{12}$ feet, and so on. If the number of feet fallen through in one second be taken as unity, then the relation of the times to the spaces will be as follows:—

Number of seconds	1	2	3	4	5	6	&c.
Units of space passed through . . .	1	4	9	16	25	36	

so that it appears that the spaces passed through by a falling body are as the squares of the times of falling.

17. *Q.*—Is not the urging force which causes bodies to fall the force of gravity?

A.—Yes; the force of gravity or the attraction of the earth.

18. *Q.*—And is not that a uniform force, or a force acting with a uniform pressure?

A.—It is.

19. *Q.*—Therefore during the first second of falling as much impelling power will be given by the force of gravity as during every succeeding second?

A.—Undoubtedly.

20. *Q.*—How comes it, then, that while the body falls $64\frac{4}{12}$ feet in two seconds, it falls only $16\frac{1}{12}$ feet in one second; or why, since it falls only $16\frac{1}{12}$ feet in one second, should it fall more than twice $16\frac{1}{12}$ feet in two?

A.—Because $16\frac{1}{12}$ feet is the average and not the maximum velocity during the first second. The velocity acquired *at the end* of the 1st second is not $16\frac{1}{12}$, but $32\frac{1}{6}$ feet per second, and at the end of the 2d second a velocity of $32\frac{1}{6}$ feet has to be added; so that the total velocity at the end of the 2d second becomes $64\frac{2}{6}$ feet; at the end of the 3d, the velocity becomes $96\frac{3}{6}$ feet, at the end of the 4th, $128\frac{4}{6}$ feet, and so on. These numbers proceed in the progression 1, 2, 3, 4, &c., so that it appears that the velocities acquired by a falling body at different points, are simply as the times of falling. But if the velocities be as the times, and the total space passed through be as the squares of the times, then the total space passed through must be as the squares of the velocity; and as the *vis viva* or mechanical power inherent in a falling body, of any given weight, is measurable by the height through which it descends, it follows that the *vis viva* is proportionate to the square of the velocity. Of two balls therefore, of equal weight, but one moving twice as fast as the other, the faster ball has four times the energy or mechanical force accumulated in it that the slower ball has. If the speed of a fly-wheel be doubled, it has four times the *vis viva* it possessed before—*vis viva* being measurable by a reference to the height through which a body must have fallen, to acquire the velocity given.

21. *Q.*—By what considerations is the *vis viva* or mechanical energy proper for the fly-wheel of an engine determined?

A.—By a reference to the power produced every half-stroke of the engine, joined to the consideration of what relation the energy of the fly-wheel rim must have thereto, to keep the irregularities of motion within the limits which are admissible. It is found in practice, that when the power resident in the fly-wheel rim, when the engine moves at its average speed, is from two and a half to four times greater than the power generated by the engine in one half-stroke—the variation depending on the energy inherent in the machinery the engine has to drive and the equability of motion required—the engine will work with sufficient regularity for most ordinary purposes, but where great equability of motion is required, it will be advisable to make the power resident in the fly-wheel equal to six times the power generated by the engine in one half-stroke.

22. *Q.*—Can you give a practical rule for determining the proper quantity of cast iron for the rim of a fly-wheel in ordinary land engines?

A.—One rule frequently adopted is as follows:—Multiply the mean diameter of the rim by the number of its revolutions per minute, and square the product for a divisor; divide the number of actual horse power of the engine by the number of strokes the piston makes per minute, multiply the quotient by the constant number 2,760,000, and divide the product by the divisor found as above; the quotient is the requisite quantity of cast iron in cubic feet to form the fly-wheel rim.

23. *Q.*—What is Boulton and Watt's rule for finding the dimensions of the fly-wheel?

A.—Boulton and Watt's rule for finding the dimensions of the fly-wheel is as follows:—Multiply 44,000 times the length of the stroke in feet by the square of the diameter of the cylinder in inches, and divide the product by the square of the number of revolutions per minute multiplied by the cube of the diameter of the fly-wheel in feet. The resulting number will be the sectional area of the rim of the fly-wheel in square inches.

CENTRAL FORCES.

24. *Q.*—What do you understand by centrifugal and centripetal forces?

A.—By centrifugal force, I understand the force with which a revolving body tends to fly from the centre; and by centripetal force, I understand any force which draws it to the centre, or counteracts the centrifugal tendency. In the conical pendulum, or steam engine governor, which consists of two metal balls suspended on rods hung from the end of a vertical revolving shaft, the centrifugal force is manifested by the divergence of the balls, when the shaft is put into revolution; and the centripetal force, which in this instance is gravity, predominates so soon as the velocity is arrested; for the arms then collapse and hang by the side of the shaft.

25. *Q.*—What measures are there of the centrifugal force of bodies revolving in a circle?

A.—The centrifugal force of bodies revolving in a circle increases as the diameter of the circle, if the number of revolutions remain the same. If there be two fly-wheels of the same weight, and making the same number of revolutions per minute, but the diameter of one be double that of the other, the larger will have double the amount of centrifugal force. The centrifugal force of the *same wheel*, however, increases as the square of the velocity; so that if the velocity of a fly-wheel be doubled, it will have four times the amount of centrifugal force.

26. *Q.*—Can you give a rule for determining the centrifugal force of a body of a given weight moving with a given velocity in a circle of a given diameter?

A.—Yes. If the velocity in feet per second be divided by 4·01, the square of the quotient will be four times the height in feet from which a body must have fallen to have acquired that velocity. Divide this quadruple height by the diameter of the circle, and the quotient is the centrifugal force in terms of the weight of the body, so that, multiplying the quotient by the actual weight of the body, we have the centrifugal force in pounds or tons. Another rule is to multiply the square of the number of revolutions per minute by the diameter of the circle in feet, and to divide the product by 5,870. The quotient is the centrifugal force in terms of the weight of the body.

27. *Q.*—How do you find the velocity of the body when its centrifugal force and the diameter of the circle in which it moves are given?

A.—Multiply the centrifugal force in terms of the weight of the body by the diameter of the circle in feet, and multiply the square root of the product by 4·01; the result will be the velocity of the body in feet per second.

28. *Q.*—Will you illustrate this by finding the velocity at which the cast iron rim of a fly-wheel 10 feet in diameter would burst asunder by its centrifugal force?

A.—If we take the tensile strength of cast iron at 15,000 lbs. per square inch, a fly-wheel rim of one square inch of sectional area would sustain 30,000 lbs. If we suppose one half of the rim to be so fixed to the shaft as to be incapable of detachment, then the centrifugal force of the other half of the rim at the moment of rupture must be equal to 30,000 lbs. Now 30,000 lbs. divided by 49·48 (the weight of the half rim) is equal to 606·3, which is the centrifugal force in terms of the weight.

Then by the rule given in the last answer 606·3 × 10 = 6063, the square root of which is 78 nearly, and 78 × 4·01 = 312·78, the velocity of the rim in feet per second at the moment of rupture.

29. *Q.*—What is the greatest velocity at which it is safe to drive a cast iron fly-wheel?

A.—If we take 2,000 lbs. as the utmost strain per square inch to which cast iron can be permanently subjected with safety; then, by a similar process to that just explained, we have 4,000 lbs. ÷ 49·48 = 80·8 which multiplied by 10 = 808, the square root of which is 28·4, and 28·4 × 4·01 = 113·884, the velocity of the rim in feet per second, which may be considered as the highest consistent with safety. Indeed, this limit should not be approached in practice on account of the risks of fracture from weakness or imperfections in the metal.

30. *Q.*—What is the velocity at which the wheels of railway trains may run if we take 4,000 lbs. per square inch as the greatest strain to which malleable iron should be subjected?

A.—The weight of a malleable iron rim of one square inch sectional area and 7 feet diameter is 21·991 feet × 3·4 lbs. = 74·76, one half of which is 37·4 lbs. Then by the same process as before, 8,000 ÷ 37·4 =213·9, the centrifugal force in terms of the weight: 213·9 × 7, the diameter of the wheel = 1497·3, the square root of which, 38·3 × 4·01 = 155·187 feet per second, the highest velocity of the rims of railway carriage wheels that is consistent with safety. 155·187 feet per second is equivalent to 105·8 miles an hour. As 4,000 lbs. per square inch of sectional area is the utmost strain to which iron should be exposed in machinery, railway wheels can scarcely be considered safe at speed even considerably under 100 miles an hour, unless so constructed that the centrifugal force of the rim will be counteracted, to a material extent, by the centripetal action of the arms. Hooped wheels are very unsafe, unless the hoops are, by some process or other, firmly attached to the arms. It is of no use to increase the dimensions of the rim of a wheel with the view of giving increased strength to counteract the centrifugal force, as every increase in the weight of the rim will increase the centrifugal force in the same proportion.

CENTRES OF GRAVITY, GYRATION, AND OSCILLATION.

31. *Q.*—What do you understand by the centre of gravity of a body?

A.—That point within it, in which the whole of the weight may be supposed to be concentrated, and which continually endeavors to gain the lowest possible position. A body hung in the centre of gravity will remain at rest in any position.

32. *Q.*—What is meant by the centre of gyration?

A.—The centre of gyration is that point in a revolving body in which the whole momentum may be conceived to be concentrated, or in which the whole effect of the momentum resides. If the ball of a governor were to be moved in a straight line, the momentum might be said to be concentrated at the centre of gravity of the ball; but inasmuch as, by its revolution round an axis, the part of the ball furthest removed from the axis moves more quickly than the part nearest to it, the momentum cannot be supposed to be concentrated at the centre of gravity, but at a point further removed from the central shaft, and that point is what is called the centre of gyration.

33. *Q.*—What is the centre of oscillation?

A.—The centre of oscillation is a point in a pendulum or any swinging body, such, that if all the matter of the body were to be collected into that point, the velocity of its vibration would remain unaffected. It is in fact the mean distance from the centre of suspension of every atom, in a ratio which happens not to be an arithmetical one. The centre of oscillation is always in a line passing through the centre of suspension and the centre of gravity.

THE PENDULUM AND GOVERNOR.

34. *Q.*—By what circumstance is the velocity of vibration of a pendulous body determined?

A.—By the length of the suspending rod only, or, more correctly, by the distance between the centre of suspension and the centre of oscillation. The length of the arc described does not signify, as the times of vibration will be the same, whether the arc be the fourth or the four hundredth of a circle, or at least they will be nearly so, and would be so exactly, if the curve described were a portion of a cycloid. In the pendulum of clocks, therefore, a small arc is preferred, as there is, in that case, no sensible deviation from the cycloidal curve, but in other respects the size of the arc does not signify.

35. *Q.*—If then the length of a pendulum be given, can the number of vibrations in a given time be determined?

A.—Yes; the time of vibration bears the same relation to the time in which a body would fall through a space equal to half the length of the pendulum, that the circumference of a circle bears to its diameter. The number of vibrations made in a given time by pendulums of different lengths, is inversely as the square roots of their lengths.

36. *Q.*—Then when the length of the second's pendulum is known the proper length of a pendulum to make any given number of vibrations in the minute can readily be computed?

A.—Yes; the length of the second's pendulum being known, the length of another pendulum, required to perform any given number of vibrations in the minute, may be obtained by the following rule: multiply the square root of the given length by 60, and divide the product by the given number of vibrations per minute; the square of the quotient is the length of pendulum required. Thus if the length of a pendulum were required that would make 70 vibrations per minute in the latitude of London, then $\frac{\sqrt{39{\cdot}1393} \times 60}{70} = 5{\cdot}363^2 = 28{\cdot}75$ in., which is the length required.

37. *Q.*—Can you explain how it comes that the length of a pendulum determines the number of vibrations it makes in a given time?

A.—Because the length of the pendulum determines the steepness of the circle in which the body moves, and it is obvious, that a body will descend more rapidly over a steep inclined plane, or a steep arc of a circle, than over one in which there is but a slight inclination. The impelling force is gravity, which urges the body with a force proportionate to the distance descended, and if the velocity due to the descent of a body through a given height be spread over a great horizontal distance, the speed of the body must be slow in proportion to the greatness of that distance. It is clear, therefore, that as the length of the pendulum determines the steepness of the arc, it must also determine the velocity of vibration.

38. *Q.*—If the motions of a pendulum be dependent on the speed with which a body falls, then a certain ratio must subsist between the distance through which a body falls in a second, and the length of the second's pendulum?

A.—And so there is; the length of the second's pendulum at the level of the sea in London, is 39·1393 inches, and it is from the length of the second's pendulum that the space through which a body falls in a second has been determined. As the time in which a pendulum vibrates is to the time in which a heavy body falls through half the length of the pendulum, as the circumference of a circle is to its diameter, and as the height through which a body falls is as the square of the time of falling, it is clear that the height through which a body will fall, during the vibration of a pendulum, is to half the length of the pendulum as the square of the circumference of a circle is to the square of its diameter; namely, as 9·8696 is to 1, or it is to the whole length of the pendulum as the half of this, namely, 4·9348 is to 1; and 4·9348 times 39·1393 in. is $16\frac{1}{12}$ ft. very nearly, which is the space through which a body falls by gravity in a second.

39. *Q.*—Are the motions of the conical pendulum or governor reducible to the same laws which apply to the common pendulum?

A.—Yes; the motion of the conical pendulum may be supposed to be compounded of the motions of two common pendulums, vibrating at right angles to one another, and one revolution of a conical pendulum will be performed in the same time as two vibrations of a common pendulum, of which the length is equal to the vertical height of the point of suspension above the plane of revolution of the balls.

40. *Q.*—Is not the conical pendulum or governor of a steam engine driven by the engine?

A.—Yes.

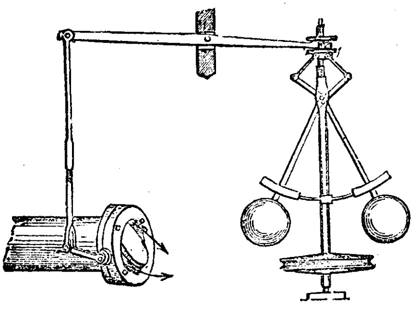
41. *Q.*—Then will it not be driven round as any other mechanism would be at a speed proportional to that of the engine?

A.—It will.

42. *Q.*—Then how can the length of the arms affect the time of revolution?

A.—By flying out until they assume a vertical height answering to the velocity with which they rotate round the central axis. As the speed is increased the balls expand, and the height of the cone described by the arms is diminished, until its vertical height is such that a pendulum of that length would perform two vibrations for every revolution of the governor. By the outward motion of the arms, they partially shut off the steam from the engine. If, therefore, a certain expansion of the balls be desired, and a certain length be fixed upon for the arms, so that the vertical height of the cone is fixed, then the speed of the governor must be such, that it will make half the number of revolutions in a given time that a

Fig. 1.



pendulum equal in length to the height of the cone would make of vibrations. The rule is, multiply the square root of the height of the cone in inches by 0·31986, and the product will be the right time of revolution in seconds. If the number of revolutions and the length of the arms be fixed, and it is wanted to know what is the diameter of the circle described by the balls, you must divide the constant number 187·58 by the number of revolutions per minute, and the square of the quotient will be the vertical height in inches of the centre of suspension above the plane of the balls' revolution. Deduct the square of the vertical height in inches from the square of the length of the arm in inches, and twice the square root of the remainder is the diameter of the circle in which the centres of the balls revolve.

43. *Q.* Cannot the operation of a governor be deduced merely from the consideration of centrifugal and centripetal forces?

A.—It can; and by a very simple process. The horizontal distance of the arm from the spindle divided by the vertical height, will give the amount of centripetal force, and the velocity of revolution requisite to produce an equivalent centrifugal force may be found by multiplying the centripetal force of the ball in terms of its own weight by 70,440, and dividing the product by the diameter of the circle made by the centre of the ball in inches; the square root of the quotient is the number of revolutions per minute. By this rule you fix the length of the arms, and the diameter of the base of the cone, or, what is the same thing, the angle at which it is desired the arms shall revolve, and you then make the speed or number of revolutions such, that the centrifugal force will keep the balls in the desired position.

44. *Q.*—Does not the weight of the balls affect the question?

A.—Not in the least; each ball may be supposed to be made up of a number of small balls or particles, and each particle of matter will act for itself. Heavy balls attached to a governor are only requisite to overcome the friction of the throttle valve which shuts off the steam, and of the connections leading thereto. Though the weight of a ball increases its centripetal force, it increases its centrifugal force in the same proportion.

THE MECHANICAL POWERS.

45. *Q.*—What do you understand by the mechanical powers?

A.—The mechanical powers are certain contrivances, such as the wedge, the screw, the inclined plane, and other elementary machines, which convert a small force acting through a great space into a great force acting through a small space. In the school treatises on mechanics, a certain number of these devices are set forth as the mechanical powers, and each separate device is treated as if it involved a separate principle; but not a tithe of the contrivances which accomplish the stipulated end are represented in these learned works, and there is no very obvious necessity for considering the principle of each contrivance separately when the principles of all are one and the same. Every pressure acting with a certain velocity, or through a certain space, is convertible into a greater pressure acting with a less velocity, or through a smaller space; but the quantity of mechanical force remains unchanged by its transformation, and all that the implements called mechanical powers accomplish is to effect this transformation.

46. *Q.*—Is there no power gained by the lever?

A.—Not any: the power is merely put into another shape, just as the contents of a hogshead of porter are the same, whether they be let off by an inch tap or by a hole a foot in diameter. There is a greater gush in the one case than the other, but it will last a shorter time; when a lever is used there is a greater force exerted, but it acts through a shorter distance. It requires just the same expenditure of mechanical power to lift 1 lb. through 100 ft., as to lift 100 lbs. through 1 foot. A cylinder of a given cubical capacity will exert the same power by each stroke, whether the cylinder be made tall and narrow, or short and wide; but in the one case it will raise a small weight through a great height, and in the other case, a great weight through a small height.

47. *Q.*—Is there no loss of power by the use of the crank?

A.—Not any. Many persons have supposed that there was a loss of power by the use of the crank, because at the top and bottom centres it is capable of exerting little or no power; but at those times there is little or no steam consumed, so that no waste of power is occasioned by the peculiarity. Those who imagine that there is a loss of power caused by the crank perplex themselves by confounding the vertical with the circumferential velocity. If the circle of the crank be divided by any number of equidistant horizontal lines, it will be obvious that there must be the same steam consumed, and the same power expended, when the crank pin passes from the level of one line to the level of the other, in whatever part of the circle it may be, those lines being indicative of equal ascents or descents of the piston. But it will be seen that the circumferential velocity is greater with the same expenditure of steam when the crank pin approaches the top and bottom centres; and this increased velocity exactly compensates for the diminished leverage, so that there is the same power given out by the crank in each of the divisions.

48. *Q.*—Have no plans been projected for gaining power by means of a lever?

A.—Yes, many plans,—some of them displaying much ingenuity, but all displaying a complete ignorance of the first principles of mechanics, which teach that power cannot be gained by any multiplication of levers and wheels. I have occasionally heard persons say: "You gain a great deal of power by the use of a capstan; why not apply the same resource in the case of a steam vessel, and increase the power of your engine by placing a capstan motion between the engine and paddle wheels?" Others I have heard say: "By the hydraulic press you can obtain unlimited power; why not then interpose a hydraulic press between the engines and the paddles?" To these questions the reply is sufficiently obvious. Whatever you gain in force you lose in velocity; and it would benefit you little to make the paddles revolve with ten times the force, if you at the same time caused them to make only a tenth of the number of revolutions. You cannot, by any combination of mechanism, get increased force and increased speed at the same time, or increased force without diminished speed; and it is from the ignorance of this inexorable condition, that such myriads of schemes for the realization of perpetual motion, by combinations of levers, weights, wheels, quicksilver, cranks, and other mere pieces of inert matter, have been propounded.

49. *Q.*—Then a force once called into existence cannot be destroyed?

A.—No; force is eternal, if by force you mean power, or in other words pressure acting though space. But if by force you mean mere pressure, then it furnishes no measure of power. Power is not measurable by force but by force and velocity combined.

50. *Q.*—Is not power lost when two moving bodies strike one other and come to a state of rest?

A.—No, not even then. The bodies if elastic will rebound from one another with their original velocity; if not elastic they will sustain an alteration of form, and heat or electricity will be generated of equivalent value to the power which has disappeared.

51. *Q.*—Then if mechanical power cannot be lost, and is being daily called into existence, must not there be a daily increase in the power existing in the world?

A.—That appears probable unless it flows back in the shape of heat or electricity to the celestial spaces. The source of mechanical power is the sun which exhales vapors that descend in rain, to turn mills, or which causes winds to blow by the unequal rarefaction of the atmosphere. It is from the sun too that the power comes which is liberated in a steam engine. The solar rays enable plants to decompose carbonic acid gas, the product of combustion, and the vegetation thus rendered possible is the source of coal and other combustible bodies. The combustion of coal under a steam boiler therefore merely liberates the power which the sun gave out thousands of years before.

FRICTION.

52. *Q.*—What is friction?

A.—Friction is the resistance experienced when one body is rubbed upon another body, and is supposed to be the result of the natural attraction which bodies have for one another, and of the interlocking of the impalpable asperities upon the surfaces of all bodies, however smooth. There is, no doubt, some electrical action involved in its production, not yet recognized, nor understood; and it is perhaps traceable to the disturbance of the electrical equilibrium of the particles of the body owing to the condensation or change of figure which all bodies must experience when subjected to a strain. When motion in opposite directions is given to smooth surfaces, the minute asperities of one surface must mount upon those of the other, and both will be abraded and worn away, in which act power must be expended. The friction of smooth rubbing substances is less when the composition of those substances is different, than when it is the same, the particles being supposed to interlock less when the opposite prominences or asperities are not coincident.

53. *Q.*—Does friction increase with the extent of rubbing surface?

A.—No; the friction, so long as there is no violent heating or abrasion, is simply in the proportion of the pressure keeping the surfaces together, or nearly so. It is, therefore, an obvious advantage to have the bearing surfaces of steam engines as large as possible, as there is no increase of friction by extending the surface, while there is a great increase in the durability. When the bearings of an engine are made too small, they very soon wear out.

54. *Q.*—Does friction increase in the same ratio as velocity?

A.—No; friction does not increase with the velocity at all, if the friction over a given amount of surface be considered; but it increases as the velocity, if the comparison be made with the time during which the friction acts. Thus the friction of each stroke of a piston is the same, whether it makes 20 strokes in the minute, or 40: in the latter case, however, there are twice the number of strokes made, so that, though the friction per stroke is the same, the friction per minute is doubled. The friction, therefore, of any machine per hour varies as the velocity, though the friction per revolution remains, at all ordinary velocities, the same. Of excessive velocities we have not sufficient experience to enable us to state with confidence whether the same law continues to operate among them.

55. *Q.*—Can you give any approximate statement of the force expended in overcoming friction?

A.—It varies with the nature of the rubbing bodies. The friction of iron sliding upon iron, has generally been taken at about one tenth of the pressure, when the surfaces are oiled and then wiped again, so that no film of oil is interposed. The friction of iron rubbing upon brass has generally been taken at about one eleventh of the pressure under the same circumstances; but in machines in actual operation, where a film of some lubricating material is interposed between the rubbing surfaces, it is not more than one third of this amount or $\frac{1}{33}$d of the weight. While this, however, is the average result, the friction is a good deal less in some cases. Mr. Southern, in some experiments upon the friction of the axle of a grindstone —an account of which may be found in the 65th volume of the Philosophical Transactions—found the friction to amount to less than $\frac{1}{40}$th of the weight; and Mr. Wood, in some experiments upon the friction of locomotive axles, found that by ample lubrication the friction may be made as little as $\frac{1}{80}$th of the weight. In some experiments upon the friction of shafts by Mr. G. Rennie, he found that with a pressure of from 1 to 5 cwt. the friction did not exceed $\frac{1}{39}$th of the pressure when tallow was the unguent employed; with soft soap it became $\frac{1}{34}$th. The fact appears to be that the amount of the resistance denominated friction depends, in a great measure, upon the nature of the unguent employed, and in certain cases the viscidity of the unguent may occasion a greater retardation than the resistance caused by the attrition. In watchwork therefore, and other fine mechanism, it is necessary both to keep the bearing surfaces small, and to employ a thin and limpid oil for the purpose of lubrication, for the resistance caused by the viscidity of the unguent increases with the amount of surface, and the amount of surface is relatively greater in the smaller class of works.

56. *Q.*—Is a very thin unguent preferable also for the larger class of bearings?

A.—The nature of the unguent, proper for different bearings, appears to depend in a great measure upon the amount of the pressure to which the bearings are subjected,—the hardest unguents being best where the pressure is greatest. The function of lubricating substances is to prevent the rubbing surfaces from coming into contact, whereby abrasion would be produced, and unguents are effectual in this respect in the proportion of their viscidity; but if the viscidity of the unguent be greater than what suffices to keep the surfaces asunder, an additional resistance will be occasioned; and the nature of the unguent selected should always have reference, therefore, to the size of the rubbing surfaces, or to the pressure per square inch upon them. With oil the friction appears to be a minimum when the pressure on the surface of a bearing is about 90 lbs. per square inch. The friction from too small a surface increases twice as rapidly as the friction from too large a surface, added to which, the bearing, when the surface is too small, wears rapidly away.

57. *Q.*—Has not M. Morin, in France, made some very complete experiments to determine the friction of surfaces of different kinds sliding upon one another?

A.—He has; but the result does not differ materially from what is stated above, though, upon the whole, M. Morin, found the resistance due to friction to be somewhat greater than it has been found to be by various other engineers. When the surfaces were merely wiped with a greasy cloth, but had no film of lubricating material interposed, the friction of brass upon cast iron he found to be ·107, or about $\frac{1}{10}$th of the load, which was also the friction of cast iron upon oak. But when a film of lubricating material was interposed, he found that the friction was the same whether the surfaces were wood on metal, wood on wood, metal on wood, or metal on metal; and the amount of the friction in such case depended chiefly on the nature of the unguent. With a mixture of hog's lard and olive oil interposed between the surfaces, the friction was usually from $\frac{1}{12}$th to $\frac{1}{14}$th of the load, but in some cases it was only $\frac{1}{20}$th of the load.

58. *Q.*—May water be made to serve for purposes of lubrication?

A.—Yes, water will answer very well if the surface be very large relatively with the pressure; and in screw vessels where the propeller shaft passes through a long pipe at the stern, the stuffing box is purposely made a little leaky. The small leakage of water into the vessel which is thus occasioned, keeps the screw shaft in this situation always wet, and this is all the lubrication which this bearing requires or obtains.

59. *Q.*—What is the utmost pressure which may be employed without heating when oil is the lubricating material?

A.—That will depend upon the velocity. When the pressure exceeds 800 lbs. per square inch, however, upon the section of the bearing in a direction parallel with the axis, then the oil will be forced out and the bearing will necessarily heat.

60. *Q.*—But, with a given velocity, can you tell the limit of pressure which will be safe in practice; or with a given pressure, can you tell the limit of velocity?

A.—Yes; that may be done by the following empirical rule, which has been derived from observations made upon bearings of different sizes and moving with different velocities. Divide the number 70,000 by the velocity of the surface of the bearing in feet per minute. The quotient will be the number of pounds per square inch of section in the line of the axis that may be put upon the bearing. Or, if we divide 70,000 by the number of pounds per square inch of section, then the quotient will be the velocity in feet per minute at which the circumference of the bearing may work.

61. *Q.*—The number of square inches upon which the pressure is reckoned, is not the circumference of the bearing multiplied by its length, but the diameter of the bearing multiplied by its length?

A.—Precisely so, it will be the diameter multiplied by the length of the bearing.

62. *Q.*—What is the amount of friction in the case of surfaces sliding upon one another in sandy or muddy water—such

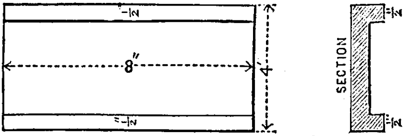
surfaces, for example, as are to be found in the sluices of valves for water?

A.—Various experiments have been made by Mr. Summers of Southampton to ascertain the friction of brass surfaces sliding upon each other in salt water, with the view of finding the power required for moving sluice doors for lock gates and for other similar purposes. The surfaces were planed as true and smooth as the planing machine would make them, but were *not* filed or scraped, and the result was as follows:

Area of Slide rubbing Surface.	Weight or Pressure on rubbing Surface.	Power required to move the Slide *slowly* in muddy Salt Water, kept stirred up.
Sq. in.	lb.	lb.
8	56	21·5
"	112	44·
"	168	65·5
"	224	88·5
"	336	140·5
"	448	170·75

Fig. 2.

Sketch of Slide.



The facing on which the slide moved was similar, but three or four times as long.

These results were the average of eight fair trials; in each case, the sliding surfaces were totally immersed in muddy salt water, and although the apparatus used for drawing the slide along was not very delicately fitted up, the power required may be considered as a sufficient approximation for practical purposes.

It appears from these experiments, that rough surfaces follow the same law as regards friction that is followed by smooth, for in each case the friction increases directly as the pressure.

STRENGTH OF MATERIALS AND STRAINS SUBSISTING IN MACHINES.

63. *Q.*—In what way are the strengths of the different parts of a steam engine determined?

A.—By reference to the amount of the strain or pressure to which they are subjected, and to the cohesive strength of the iron or other material of which they are composed. The strains subsisting in engines are usually characterized as tensile, crushing, twisting, breaking, and shearing strains; but they may be all resolved into strains of extension and strains of compression; and by the power of the materials to resist these two strains, will their practical strength be measurable.

64. *Q.*—What are the ultimate strengths of the malleable and cast iron, brass, and other materials employed in the construction of engines?

A.—The tensile and crushing strengths of any given material are by no means the same. The tensile strength, or strength when extended, of good bar iron is about 60,000 lbs., or nearly 27 tons per square inch of section; and the tensile strength of cast iron is about 15,000 lbs., or say 6¾ to 7 tons per square inch of section. These are the weights which are required to break them. The crushing strain of cast iron, however, is about 100,000 lbs., or 44½ tons; whereas the crushing strength of malleable iron is not more than 27,000 lbs., or 12 tons, per square inch of section, and indeed it is generally less than this. The ultimate tensile strength, therefore, of malleable iron is four times greater than that of cast iron, but the crushing strength of cast iron is between three and four times greater than that of wrought iron. It may be stated, in round numbers, that the tensile strength of malleable iron is twice greater than its crushing strength; or, in other words, that it will take twice the strain to break a bar of malleable iron by drawing it asunder endways, than will cripple it by forcing it together endways like a pillar; whereas a bar of cast iron will be drawn asunder with one sixth of the force that will be required to break or cripple it when forced together endways like a pillar.

65. *Q.*—What is the cohesive strength of steel?

A.—The ultimate tensile strength of good cast or blistered steel is about twice as great as that of wrought iron, being about 130,000 lbs. per square inch of section. The tensile strength of gun metal, such as is used in engines, is about 36,000 lbs. per square inch of section; of wrought copper about 33,000 lbs.; and of cast copper about 19,000 lbs. per square inch of section.

66. *Q.*—Is the crushing strength of steel greater or less than its tensile strength?

A.—It is about twice greater. A good steel punch will punch through a plate of wrought iron of a thickness equal to the diameter of the punch. A punch therefore of an inch diameter will pierce a plate an inch thick. Now it is well known, that the strain required to punch a piece of metal out of a plate, is just the same as that required to tear asunder a bar of iron of the same area of cross section as the area of the surface cut. The area of the surface cut in this case will be the circumference of the punch, 3·1416 inches, multiplied by the thickness of the plate, 1 inch, which makes the area of the cut surface 3·1416 square inches. The area of the point of the punch subjected to the pressure is ·7854 square inches, so that the area cut to the area crushed is as four to one. In other words, it will require four times the strain to crush steel that is required to tear asunder malleable ion, or it will take about twice the strain to crush steel that it will require to break it by extension.

67. *Q.*—What strain may be applied to malleable iron in practice?

A.—A bar of wrought iron to which a tensile or compressing strain is applied, is elongated or contracted like a very stiff spiral spring, nearly in the proportion of the amount of strain applied up to the limit at which the strength begins to give way, and within this limit it will recover its original dimensions when the strain is removed. If, however, the strain be carried beyond this limit, the bar will not recover its original dimensions, but will be permanently pulled out or pushed in, just as would happen to a spring to which an undue strain had been applied.

This limit is what is called the limit of elasticity; and whenever it is exceeded, the bar, though it may not break immediately, will undergo a progressive deterioration, and will break in the course of time. The limit of elasticity of malleable iron when extended, or, in other words, the tensile strain to which a bar of malleable iron an inch square may be subjected without permanently deranging its structure, is usually taken at 17,800 lbs., or from that to 10 tons, depending on the quality of the iron. It has also been found that malleable iron is extended about one ten-thousandth part of its length for every ton of direct strain applied to it.

68. *Q.*—What is the limit of elasticity of cast iron?

A.—It is commonly taken at 15,300 lbs. per square inch of section; but this is certainly much too high, as it exceeds the tensile strength of irons of medium quality. A bar of cast iron if compressed by weights will be contracted in length twice as much as a bar of malleable iron under similar circumstances; but malleable iron, when subjected to a greater strain than 12 tons per square inch of section, gradually crumples up by the mere continuance of the weight. A cast-iron bar one inch square and ten feet long, is shortened about one tenth of an inch by a compressing force of 10,000 lbs., whereas a malleable iron bar of the same dimensions would require to shorten it equally a compressing force of 20,000 lbs. As the load, however, approaches 12 tons, the compressions become nearly equal, and above that point the rate of the compression of the malleable iron rapidly increases. A bar of cast iron, when at its breaking point by the application of a tensile strain, is stretched about one six-hundredth part of its length; and an equal strain employed to compress it, would shorten it about one eight-hundredth part of its length.

69. *Q.*—But to what strain may the iron used in the construction of engines be safely subjected?

A.—The most of the working parts of modern engines are made of malleable iron, and the utmost strain to which wrought iron should be subjected in machinery is 4000 lbs. per square inch of section. Cast iron should not be subjected to more than half of this. In locomotive boilers the strain of 4000 lbs. per square inch of section is sometimes exceeded by nearly one half; but such an excess of strain approaches the limits of danger.

70. *Q.*—Will you explain in what way the various strains subsisting in a steam engine may be resolved into tensile and crushing strains; also in what way the magnitude of those strains may be determined?

A.—To take the case of a beam subjected to a transverse strain, such as the great beam of an engine, it is clear, if we suppose the beam broken through the middle, that the amount of strain at the upper and lower edges of the beam, where the whole strain may be supposed to be collected, will, with any given pressure on the piston, depend upon the proportion of the length to the depth of the beam. One edge of the beam breaks by extension, and the other edge by compression; and the upper and lower edges may be regarded as pillars, one of which is extended by the strain, and the other is compressed. If, to make an extreme supposition, the depth of the beam is taken as equal to its length, then the pillars answering to the edges of the beam will be compressed, and extended by what is virtually a bellcrank lever with equal arms; the horizontal distance from the main centre to the end of the beam being one of the arms, and the vertical height from the main centre to the top edge of the beam being the other arm. The distance, therefore, passed through by the fractured edge of the beam during a stroke of the engine, will be equal to the length of the stroke; and the strain it will have to sustain will consequently be equal to the pressure on the piston. If its motion were only half that of the piston, as would be the case if its depth were made one half less, the strain the beam would have to bear would be twice as great; and it may be set down as an axiom, that the strain upon any part of a steam engine or other machine is inversely equal to the strain produced by the prime mover, multiplied by the comparative velocity with which the part in question moves. If any part of an engine moves with a less velocity than the piston, it will have a greater strain on it, if resisted, than is thrown upon the piston. If it moves with a greater velocity than the piston, it will have a less strain upon it, and the difference of strain will in every case be in the inverse proportion of the difference of the velocity.

71. *Q.*—Then, in computing the amount of metal necessary to give due strength to a beam, the first point is to determine the velocity with which the edge of the beam moves at that point were the strain is greatest?

A.—The web of a cast-iron beam or girder serves merely to connect the upper and lower edges or flanges rigidly together, so as to enable the extending and compressing strains to be counteracted in an effectual manner by the metal of those flanges. It is only necessary, therefore, to make the flanges of sufficient strength to resist effectually the crushing and tensile strains to which they are exposed, and to make the web of the beam of sufficient strength to prevent a distortion of its shape from taking place.

72. *Q.*—Is the strain greater from being movable or intermittent than if it was stationary?

A.—Yes it is nearly twice as great from being movable. Engineers are in the habit of making girders intended to sustain a stationary load, about three times stronger than the breaking weight; but if the load be a movable one, as is the case in the girders of railway bridges, they make the strength equal to six times the breaking weight.

73. *Q.*—Then the strain is increased by the suddenness with which it is applied?

A.—If a weight be placed on a long and slender beam propped up in the middle, and the prop be suddenly withdrawn, so as to allow deflection to take place, it is clear that the deflection must be greater than if the load had been gradually applied. The momentum of the weight and also of the beam itself falling through the space through which it has been deflected, has necessarily to be counteracted by the elasticity of the beam; and the beam will, therefore, be momentarily bent to a greater extent than what is due to the load, and after a few vibrations up and down it will finally settle at that point of deflection which the load properly occasions. It is obvious that a beam must be strong enough, not merely to sustain the pressure due to the load, but also that accession of pressure due to the counteracted momentum of the weight and of the beam itself. Although in steam engines the beam is not loaded by a weight, but by the pressure of the steam, yet the momentum of the beam itself must in every case be counteracted, and the momentum will be considerable in every case in which a large and rapid deflection takes place. A rapid deflection increases the amount of the deflection as well as the amount of the strain, as is seen in the cylinder cover of a Cornish pumping engine, into which the steam is suddenly admitted, and in which the momentum of the particles of the metal put into motion increases the deflection to an extent such as the mere pressure of the steam could not produce.

74. *Q.*—What will be the amount of increased strain consequent upon deflection?

A.—The momentum of any moving body being proportional to the square of its velocity, it follows that the strain will be proportional to the square of the amount of deflection produced in a specified time.

75. *Q.*—But will not the inertia of a beam resist deflection, as well as the momentum increase deflection?

A.—No doubt that will be so; but whether in practical cases increase of mass without reference to strength or load will, upon the whole, increase or diminish deflection, will depend very much upon the magnitude of the mass relatively with the magnitude of the deflecting pressure, and the rapidity with which that pressure is applied and removed. Thus if a force or weight be very suddenly applied to the middle of a ponderous beam, and be as suddenly withdrawn, the inertia of the beam will, as in the case of the collision of bodies, tend to resist the force, and thus obviate deflection to a considerable extent; but if the pressure be so long continued as to produce the amount of deflection due to the pressure, the effect of the inertia in that case will be to increase the deflection.

76. *Q.*—Will the pressure given to the beam of an engine in different directions facilitate its fracture?

A.—Iron beams bent alternately in opposite directions, or alternately deflected and released, will be broken in the course of time with a much less strain than is necessary to produce immediate fracture. It has been found, experimentally, that a cast-iron bar, deflected by a revolving cam to only half the extent due to its breaking weight, will in no case withstand 900 successive deflections; but, if bent by the cam to only one third of its ultimate deflection, it will withstand 100,000 deflections without visible injury. Looking, however, to the jolts and vibrations to which engines are subject, and the sudden strains sometimes thrown upon them, either from water getting into the cylinder or otherwise, it does not appear that a strength answering to six times the breaking weight will give sufficient margin for safety in the case of cast-iron beams.

77. *Q.*—Does the same law hold in the case of the deflection of malleable iron bars?

A.—In the case of malleable iron bars it has been found that no very perceptible damage was caused by 10,000 deflections, each deflection being such as was due to half the load that produced a large permanent deflection.

78. *Q.*—The power of a rod or pillar to resist compression becomes very little when the diameter is small and the length great?

A.—The power of a rod or pillar to resist compression, varies nearly as the fourth power of the diameter divided by the square of the length. In the case of hollow cylindrical columns of cast iron, it has been found, experimentally, that the 3·55th power of the internal diameter, subtracted from the 3·55th power of the external diameter, and divided by the 1·7th power of the length, will represent the strength very nearly. In the case of hollow cylindrical columns of malleable iron, experiment shows that the 3·59th power of the internal diameter, subtracted from the 3·59th power of the external diameter, and divided by the square of the length, gives a proper expression for the strength; but this rule only holds where the strain does not exceed 8 or 9 tons on the square inch of section. Beyond 12 or 13 tons per square inch of section, the metal cannot be depended upon to withstand the strain, though hollow pillars will sometimes bear 15 or 16 tons per square inch of section.

79. *Q.*—Does not the thickness of the metal of the pillars or tubes affect the question?

A.—It manifestly does; for a tube of very thin metal, such as gold leaf or tin foil, would not stand on end at all, being crushed down by its own weight. It is found, experimentally, that in malleable iron tubes of the respective thicknesses of ·525, ·272, and ·124 inches, the resistances per square inch of section are 19·17, 14·47, and 7·47 tons respectively. The power of plates to resist compression varies nearly as the cube, or more nearly as the 2·878th power of their thickness; but this law only holds so long as the pressure applied does not exceed from 9 to 12 tons per square inch of section. When the pressure is greater than this the metal is crushed, and a new law supervenes, according to which it is necessary to employ plates of twice or three times the thickness, to obtain twice the resisting power.

80. *Q.*—In a riveted tube, will the riveting be much damaged by heavy strains?

A.—It will be most affected by percussion. Long-continued impact on the side of a tube, producing a deflection of only one fifth of that which would be required to injure it by pressure, is found to be destructive of the riveting; but in large riveted structures, such as a ship or a railway bridge, the inertia of the mass will, by resisting the effect of impact, prevent any injurious action from this cause from taking place.

81. *Q.*—Will the power of iron to resist shocks be in all cases proportional to its power to resist strains?

A.—By no means. Some cast iron is very hard and brittle; and although it will in this state resist compression very strongly, it will be easily broken by a blow. Iron which has been remelted many times generally falls into this category, as it will also do if run into very small castings. It has been found, by experiment, that iron of which the crushing weight per square inch is about 42 tons, will, if remelted twelve times, bear a crushing weight of 70 tons, and if remelted eighteen times it will bear a crushing weight of 83 tons; but taking its power to resist impact in its first state at 706, this power will be raised at the twelfth remelting to 1153, and will be sunk at the eighteenth remelting to 149.

82. *Q.*—From all this it appears that a combination of cast iron and malleable iron is the best for the beams of engines?

A.—Yes, and for all beams. Engine beams should be made deeper at the middle than they are now made; the web should be lightened by holes pierced in it, and round the edge of the beam there should be a malleable iron hoop or strap securely attached to the flanges by riveting or otherwise. The flanges at the edges of engine beams are invariably made too small. It is in them that the strength of the beam chiefly resides.