# CHAPTER XIX.

## MODERN MILL CONSTRUCTION: HEATING, LIGHTING, VENTILATION AND HUMIDIFICATION.

*Site for Mills.*—In choosing the site for a mill some of the principal considerations are:—A good supply of hands (trained if possible); an unfailing and sufficient supply of water for condensing and other purposes (if the same can be used as a source of power, so much the better), proximity to a railway, canal or river, in order that coals, fibre and yarn may be delivered as cheaply as possible; and lastly, the vicinity of a ready market for the finished products.

For the spinning of fine yarns some climates and local meteorological conditions are more favourable than others. Ireland and Belgium, for instance, have become seats of the linen trade, which remains and flourishes there, while other countries, such as the United States of America, although taking the lead in other branches of industry, must own, after frequent attempts, that their country and climate are not suitable for the spinning of linen yarns, especially in the finer counts. It has long been recognised as a fact that the state of the atmosphere as regards moisture has a great effect upon the ease with which the spinning of vegetable fibres can be accomplished. Those countries and districts in which the rainfall is frequent and considerable, or which have large areas covered with water, which is constantly being evaporated and absorbed by the surrounding atmosphere, are found to be most suited to the spinning of such fibres.

As regards the buildings themselves, if they are to be well-built sheds or many-storeyed mills, a solid and dry foundation should be sought for. If the soil be clayey, a concrete foundation made with hydraulic lime should be provided, to avoid damp walls.

*Mill Buildings.*—A hand rope walk is the simplest form of building, being frequently little more than a long narrow shed of wood with a tarred felt roof. In length it should not be less than 900 feet, so that ropes of a minimum length of 120 fathoms may be produced.

Main mill buildings should, if possible, stand due north and south, in order that advantage may be taken of the first and last rays of daylight, and the lighting bill thereby reduced. The most favoured form of main building for flax, fine hemp, jute and ramie spinning is a rectangle, usually of five storeys, from 150 feet to 200 feet in length and 45 feet to 50 feet in breadth.

On the Continent mills often exceed the latter dimensions as regards width, as longer frames are often employed, because, as is said, spinners wearing wooden shoes cannot turn easily and without danger, and consequently mind only one long side. For wet spinning the bays should be 9 feet wide, which, with piers of 3 feet 8 inches in breadth, gives a window 5 feet 4 inches in width between each pair of spinning frames. For dry spinning the frames are wider, as should also be the bays in which they stand.

The placing of the windows between the frames is an important point as regards light. The height of the rooms on the ground, first, second and third floors is from 12 to 13 feet. The top storey is usually lower, say 8 feet. The height of the windows is from 9 feet 6 inches to 10 feet 6 inches. According to the usual construction the floors are fireproof and supported by cast iron girder beams, and by rows of cast iron columns 8 inches to 10 inches in diameter, according to the storey. Wide mills of old construction have generally two rows of such columns, which are most inconvenient, in that the frames must be placed opposite the windows or else the columns pass through the centre of the frames. Old mills which are not too wide, and new mills in which proportionately heavy girder beams are used, have but one row of columns placed out of the centre and to one side of the centre spinning room pass.

Bricks and mortar of good quality must be employed, and the piers should be of sufficient section to bear the weight of the storeys above filled with heavy machinery.

The roof is often made flat with a parapet forming a reservoir of water for the spinning room, and, in the case of country mills, giving a supply of water under pressure in case of fire. The pressure in pounds per square inch of the water taken at any point is the product of the difference in level in feet and the decimal fraction 0·4. Thus if the level of the water in the reservoir be 50 feet above the ground, the greatest pressure of water obtainable from it will be $50 \times 0{\cdot}4 = 20$ lbs. per square inch, or about 1·3 atmospheres.

*Heating and Ventilation.*—New mills should be designed with a view to their proper heating and ventilation. As regards the general ventilation of a flax, hemp or jute mill, the dust generated in the hackling, carding and preparing departments is of such a character and volume as to require special means of removing it. These rooms are therefore generally treated separately in various ways, which we will presently describe. The wet spinning room, and the reeling room if ventilated at all, may be kept in a healthy state by the use of fans of the Blackman type set in the wall and extracting the damp and vitiated air from the room, the balance of pressure being maintained by the entry of air through the doors and other apertures. This is termed the vacuum method of ventilation, and presents the inconvenience that the air which replaces that which is removed may and *does* find its way in anywhere, it may be even from drains or closets. The plenum method of ventilation is rather to be recommended, in that the fresh air is introduced from outside and is therefore pure, the vitiated air being expelled by the excess of pressure inside the room. Such an installation is that made by the Sturtevant Engineering Co., the usual arrangement being as depicted in fig. 133, in which it will be seen that a large fan or blower is located in the basement, draws in the outside air, and, passing it through or over

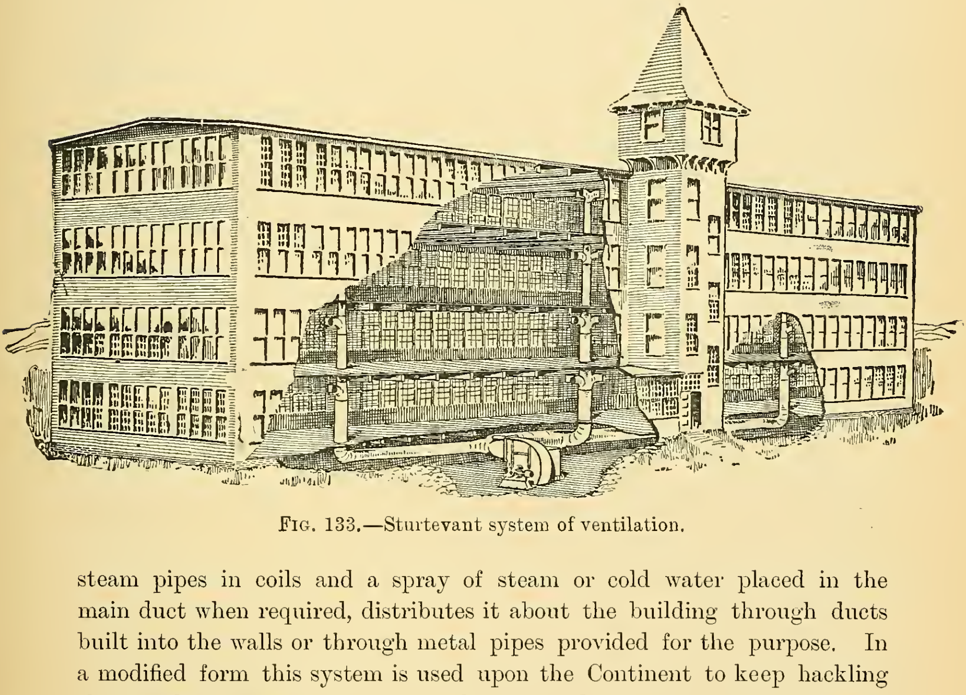

FIG. 133.—Sturtevant system of ventilation.

steam pipes in coils and a spray of steam or cold water placed in the main duct when required, distributes it about the building through ducts built into the walls or through metal pipes provided for the purpose. In a modified form this system is used upon the Continent to keep hackling shops and preparing rooms free of dust. To do so it is merely necessary to connect up the inlet of air to the fan with a large duct the ramifications of which extend under the floors of the rooms to be cleared, with which they communicate by openings of section proportional to their distance from the fan. These openings may be situated immediately underneath the machines which produce the dust, such as the hackling machine and drawing frame, and thus catch the dust as produced, the downward current of air preventing it from rising and polluting the atmosphere of the room. A water spray is placed on the inlet side of the fan, and effectually washes and purifies the air before it is returned into the room. The dust falls, and is washed away by the waste water from the spray. A plenum is still maintained in the room, for the fan always drives in more air than it extracts, on account of the fresh air which it cannot be prevented from taking in through the water gutter, etc.

Thus a new mill may be designed with a view to a system of heating and ventilation such as we have described. Air ducts for both inlet and outlet may be built into the walls, underground ducts may be dug out and cemented for the ground floor rooms, while the upstairs rooms may have double ceilings or floors giving space for the requisite horizontal branches of the vertical air ducts. The ducts admitting air should be in the ceiling, thus avoiding draughts and preventing the rise of dust.

*Roofs.*—Substantially built sheds for ropeworks, etc., may be composed of bays about 18 feet wide and 12 to 13 feet high to the gutter. The roof should be of the saw-tooth pattern, the least sloping side being glazed. It is usually supported by beams, say 12 inches by 8 inches, and cast iron columns 6 inches in diameter and about 10 feet pitch. If a shed be humidified, it is generally necessary to make the roof double, and to fill it with cork or other non-conductor, in order to prevent excessive condensation at night when the temperature falls. This roof will also keep the shop cooler in hot weather. The Continental type of double-tiled roof lends itself particularly well to this operation.

*Chimneys.*—The building of the mill chimney must be carefully watched in order that it may remain perfectly straight and withstand the effects of the weather. A good foundation of concrete should first be provided, its dimensions depending upon the height and weight of the chimney, and the nature of the soil. Building should not proceed too quickly, in order that the mortar may dry before too much weight comes upon it. This is an important point, as, if the weather be wet, the mortar on that side which is most exposed to the rain, remains soft, and a bent chimney is the result. There is not nearly so much danger of this occurring if hydraulic lime be used in the mortar.

The bricks intended to form the corners of square and polygonal chimneys should be rather thicker than the rest, so that the jointing will be of necessity closer and stand the effects of the weather to which the corners are particularly exposed. A lightning conductor should always be provided, and be placed on the side of the chimney which is most exposed to rain. It should be composed of one or more points connected by a copper tape with a large copper plate buried in the ground at the base of the chimney.

*Heating and Lighting.*—If the heating of the mill be quite independent of its ventilation, it is best accomplished by means of high pressure steam, which will be found to be the most economical, if the piping be arranged to form a circuit and to return the water of condensation under the check valve into the boiler.

Electric lighting has almost entirely superseded gas for mill lighting. However, there are still some mills making their own gas. Coal gas, oil gas, and water gas enriched with oil, are all employed for mill-lighting purposes. Nos. 6 and 7 burners are those usually employed, the former giving about 14, and the latter 16-candle power light with good gas. The standard of candle power is the amount of light produced by a standard candle weighing 6 per lb. and burning 120 grains of spermaceti wax per hour.

The electric current used to produce light for the mill with the aid of arc and incandescent lamps is usually generated by a dynamo driven by ropes or a belt from the shafting or mill engine. The size or capacity of a dynamo is usually expressed in watts, and is the product of the ampères of current it can furnish and the voltage or pressure of that current. An ohm is the unit of electrical resistance. A copper wire $\frac{1}{4}$ inch in diameter and a mile long offers a resistance of one ohm to the passage of the current. When a wire of an ohm resistance has its two ends kept at a difference of potential of one volt, there is a current of unit strength called an ampère in the wire. A volt is the electromotive force which in a circuit of one ohm resistance produces a current of one ampère. The electro-motive force in volts of current equals the current in ampères multiplied by the resistance in ohms, therefore the volts lost in a circuit equal the product of the ampères and ohms. To find the resistance of a cable 19/12 in a circuit 400 yards long, it being known that the resistance of a mile of 19/12 cable is ·2709 ohms, we find by proportion that the resistance of $400 \times 2 = 800$ yards, is ·117 ohms. If a current of 40 ampères be sent through the wire, by the time the current has reached the end of the 400 yards it has lost $40 \times {\cdot}117 = 4{\cdot}68$ volts.

Each candle power of light produced absorbs about 3·5 watts. When current is purchased from an electrical supply company it is measured in Board of Trade units, each of which is equivalent to 1 kilowatt hour. A kilowatt equals 1000 watts.

Dynamos are made with two, four, or more poles, and have a corresponding number of rows of brushes, which rest upon the collector and take off the current as produced. Carbon brushes upon a copper collector give the least trouble and spark the least.

Lamps are of two kinds—arc and incandescent or glow lamps. In the former, which take less force for a given candle power produced, the light is produced by the heating to incandescence of the ends of carbon pencils by reason of the heat engendered by the resistance experienced by the current in passing between their points, which are separated by a fraction of an inch. In the glow lamp, a fine filament of carbon, which offers a great resistance to the passage of the current, is heated to incandescence in a hermetically sealed glass bulb in which a vacuum has been established. Were air present in the bulb the carbon filament would burn away immediately. If the dynamo is overloaded it is advisable to use glow lamps of low wattage, although they will not last long, especially if subject to vibration. Arc lamps are usually connected up in series of three lamps, and do very well for large works such as ropeworks, etc. The inverted type which throw the light upwards—upon a white ceiling, for instance, which reflects it downwards—are to be preferred, when possible, owing to the absence of shadows. For fine spinning rooms the incandescent lamp is to be preferred, two or three being placed in each spinner's stand at a height of about four feet above the floor level. There are four ways of connecting up electric lamps :

In series—that is, in single file. Arc lamps are generally connected in this way, so that the potential or voltage between the ends of the series must be the voltage required by one lamp multiplied by the number of lamps in the circuit. The current remains the same for any number of lamps.

In single parallel—that is, like a ladder ; one lamp is in each step and the two sides form the main conductors. Glow lamps are generally connected up in this way, so that the potential or voltage between the conductors remains constant. The current varies according to the number of lamps.

In series parallel—that is, when more than one lamp is placed in each step of the ladder.

The three-wire system consists in the use of three parallel main wires, the centre one being the return wire, thus forming a sort of double parallel.

The theory of electricity is not difficult if it be borne in mind that the same laws which govern the flow of water may be applied to the electric current. If water circulate in pipes there is a loss of pressure due to friction, just as with electricity there is a loss of voltage when the current is sent through a conductor. The electric current, in forming a short circuit, takes the line of least resistance, just as water would do under like circumstances, and so on.

*Air Supply.*—Returning again to the question of ventilation and humidity. The Factory Act of 1889 provides that every apartment of a factory where artificial humidity is produced must be provided with means for the admission of at least 600 cubic feet of fresh air per hour for each person employed therein.

Again, under the Special Rules which the Secretary of State was authorised to make, by the Factory Act of 1891, for the spinning of flax, it was specified that in roughing and sorting shops, exhaust fans were to be provided so as to draw the dust forward and down from the face of the worker. Under the same rules the carding and preparing rooms had also to be provided with fans.

In the Factory Act of 1895 it is enacted that 250 cubic feet of air space shall be provided for each person employed. This rule, taken in conjunction with a supply of 600 cubic feet of fresh air per head and per hour, means, that if the space is just legally sufficient for the number of hands employed, the air must be changed rather more than twice per hour.

In most modern mills the amount of air space per hand is well over the minimum, so that in many cases a complete renovation of the whole atmosphere *once* per hour is ample. In order that one may form an opinion as to the number of fans necessary to fulfil these conditions in any sized apartment, some idea must be gained as to the number of cubic feet of air which fans of various diameters and speeds can pass per minute or per hour. Taking the well-known Blackman fan as a standard for that type, a 14-inch fan will "blow in" or exhaust approximately one cubic foot of air per revolution per minute, or running at the usual speed of 1000 to 1500 revolutions per minute, it will move on the average, say $1250 \times 60 =$ 75,000 cubic feet per hour. One such fan, then, should provide $\frac{75000}{900} =$ 125 persons with 600 cubic feet of fresh air per head per hour, in compliance with the Act. Larger fans run at speeds inversely as the pitch of their blades will move quantities of air approximately proportional to the area of their delivery surface.

If the average velocity of the air passed by the fan be known in feet per minute, its volume in cubic feet is the product of the former and the area of the delivery surface in square feet. The velocity of the air, of course, varies with the speed of the fans. In Blackman fans driven at the usual speed, it varies from 1000 to 2400 feet per minute. The instrument employed in finding the velocity of air currents is called an anemometer, an improved form of which, as made by the Sturtevant Engineering Co., we show in fig. 134. The action of an anemometer depends either upon the velocity imparted to a vertical spindle by the air current acting upon hemispherical vanes placed upon the end of radial arms, or on the pressure exerted by the current upon a plate directly exposed to it and measured by the compression of a spring, or on the height of a water column supported by the same pressure. As regards the latter it may be said that the height of the water column supported is directly as the square of the velocity of the air, and that an air current with a velocity of 1430 feet per minute will support a water column a quarter inch in length.

In the ordinary method of ventilation the fans are usually set in frames in the outer walls of the building, or in a part of the window frame, the spindle of the fan being horizontal and at right angles to its frame.

For the ventilation of sheds, some recommend that the fans should be fixed with a vertical spindle, so that they will work horizontally about 8 or 10 inches below the gutter line, thus giving a horizontal and diagonal draw upon the air, removing the hot atmosphere which rises to the top of the room without causing any draught upon the workers.

*Humidity of Air Supply.*—The humidity of the atmosphere exercises an important influence on the ease with which the preparing and spinning operations of vegetable fibres are accomplished.

In the flax and tow preparing room, the drawers find on a cold frosty morning, or when a dry March wind is blowing, that if the slivers do not actually lap themselves upon the pressing rollers, so much fibre is carried away by the rollers and deposited upon the rubbers, that the sliver is rendered lighter by an appreciable amount.

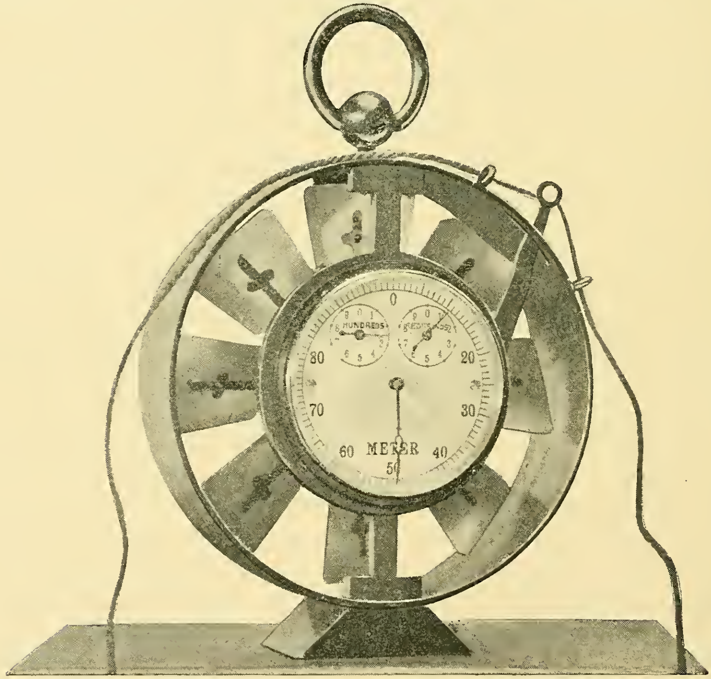

FIG. 134.—Improved anemometer, as supplied by the Sturtevant Engineering Co.

Under such conditions, too, the rove is much more "hairy," and requires more twist to strengthen it, on account of the fibres not binding so well together through the lack of moisture.

No air is ever absolutely dry, although in the British Isles the east wind is often very dry.

Sometimes we experience an opposite state of the atmosphere when the air is saturated with moisture which condenses on every heat-absorbing object.

The air on a summer day, which we would consider to be fairly dry, might in reality contain a much larger quantity of moisture than does the air upon a winter's day when much rain has fallen. It is not the quantity of moisture contained in the air with which we must concern ourselves; it is its capacity for absorbing more. Warm air is capable of holding in suspension a much larger quantity of aqueous vapour than is cold air. When air at any temperature contains as much moisture as it is capable of absorbing, it is said to be saturated. Dew point is the temperature at which air is just saturated with a given quantity of moisture. If the dew point is high, the air contains a large quantity of moisture. If the air contains a small quantity of moisture, the dew point is correspondingly low. The temperature of dew point is best obtained with the aid of a hygrometer (previously described and shown in fig. 65) in the following manner:—

Multiply the difference between the temperatures of the wet and dry bulb by Glaisher's factor, which corresponds with the temperature of the air at the time of observation, and subtracting the product thus obtained from the temperature as indicated on the dry bulb, we get the temperature of the dew point. Glaisher's factors vary from 3·1 for 32° F. to 1 for 85° F., so that the factor for 75° F. being 1·5, the temperature of dew-point when the dry bulb indicates 75° F. and the wet bulb 73° F. is $75° \text{ F.} - [(75 - 73)1{\cdot}5] = 72° \text{ F.}$ It is by reason of the variation in Glaisher's factor that the Factory Act of 1889 requires that the difference in reading of the wet and dry bulb thermometers should vary from 2 degrees at a temperature of 60° F. to 8 degrees at a temperature of 95° F. in order that the temperature of the dew point may be well below the temperature of the atmosphere, which will then be relatively dry.

A convenient form of automatic self-registering apparatus supplied by a Paris firm shows the humidity of the atmosphere from hour to hour and day to day. Its working is based on the expansion and contraction of a twisted thread of human hair which acts upon a finger arm, a pen upon the end of which traces a line upon a strip of paper which passes around a drum moved by clockwork.

In figs. 135 and 136 we show the improved Drosphore humidifier, which may be used with good effect in preparing and dry spinning rooms. Water under pressure is conveyed to the machine by a galvanised wrought iron pipe marked "inlet" in fig. 135.

The lower pipe, marked "outlet," receives the waste water, which returns to a tank fixed in a convenient place, where the water is filtered and used over again, so that none need run to waste. If a supply of water at 100 lbs. pressure is available it may be utilised, otherwise a small pump is required to get up the necessary pressure. The nozzle by means of which the water spray is formed is shown in section in fig. 136. The orifice of the nozzle may be washed when required by pulling the lever shown, when a quantity of water is allowed to pass, which also cleanses the filter and flushes the return of the apparatus. When at work the water issues in the form of a fine mist all around the lower part of the machine, as shown in fig. 135. About 60,000 cubic feet of air per hour may be humidified with this apparatus.

A simple but effective method of purifying and humidifying the atmosphere of a room is that of Kestner. An air pipe surrounds three sides of the room. A fan is placed in one corner of the U thus formed and draws air through apertures in the opposite leg of the U, and at the same time a certain quantity of water which is spread over the internal surface of the tube by the force of the air current. The dust and fluff is retained by the damp sides of the tube and washed away with the surplus water, while the air is humidified in passing along two sides of the U and returned into the room through apertures in the third side after passing through the fan.

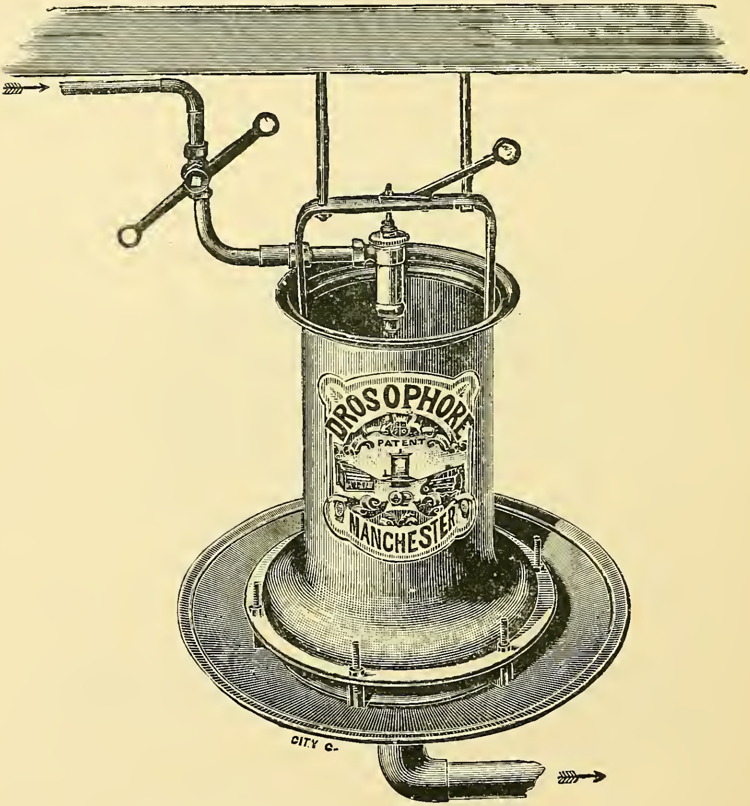

Fig. 135.—The improved "Drosophore" humidifier.

*Systems of Ventilation:—Wilson-Clyma's.*—One of the special methods of flax, hemp, tow and jute carding room ventilation is shown in figs. 137, 138, and 139. This system is associated with the name of Mr T. E. Wilson-Clyma of Ghent and Lille, who has made it the subject of several patents, brought it to a high state of perfection, and introduced it into many important mills in Belgium and the North of France. Fig. 137 shows the yard of one of the most important flax mills which exist—the Société Linière Gantoise, the cyclone dust depositers and separators with dust chambers being clearly seen. It is in this mill, where it is applied to more than a hundred cards, that the system has reached its present state of efficiency. In figs. 138 and 139, E are conical excavations or card pits, the sides inclined and covered with glazed tiles, offering a perfectly smooth surface to allow the card waste to slip down, as it falls, to the ducts B of glazed earthenware pipes. A powerful fan D draws away the dust and waste and throws it up into the cyclone-separator C, which is constructed in such a

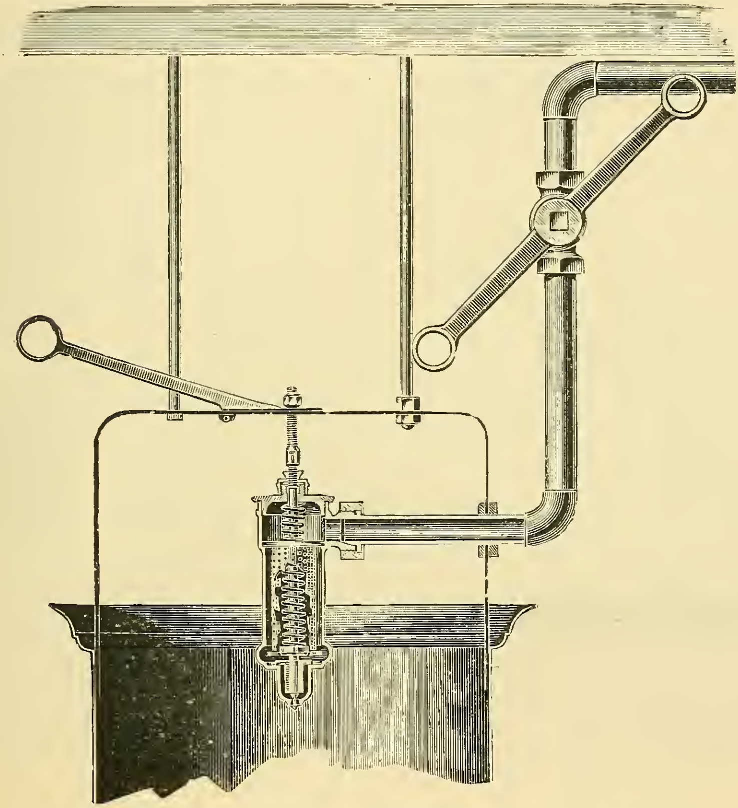

FIG. 136.—The "Drosophore" humidifier; section of the nozzle.

way that the heavy waste falls downwards into the chamber F, while the air escapes from the upper portion of the cyclone. The system works well if the sides of the pit are inclined at a proper angle, and if the ducts are of sufficient section. The amount of card waste is not increased by the suction of the fan, which is not intense, except at the apex of the cone and mouth of the duct, which are far removed from the card cylinder, and of comparatively small section. Practical experience has shown that the danger of fire being communicated from one card to another is not increased.

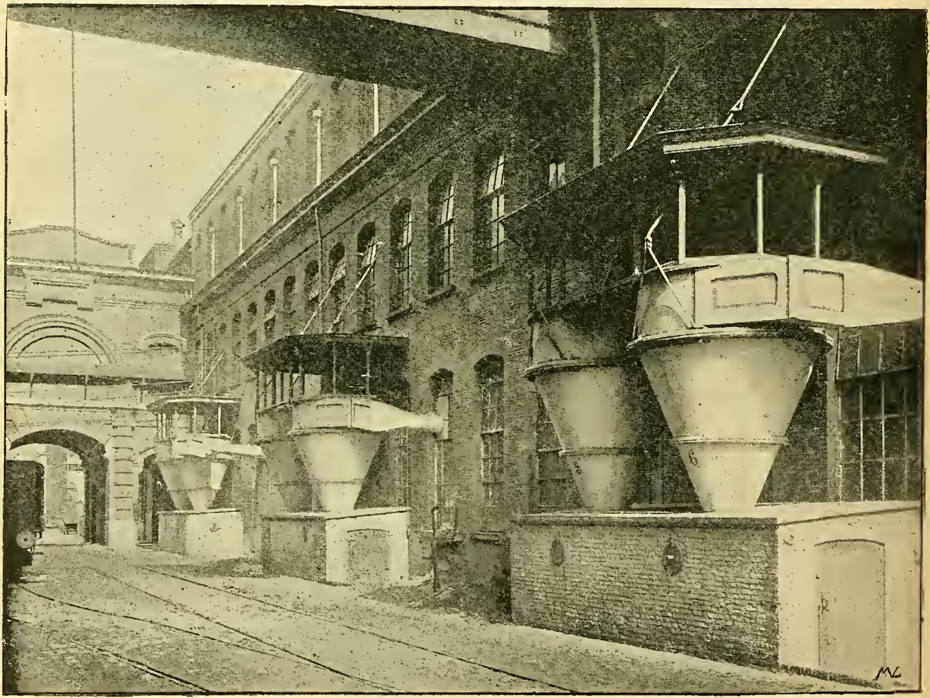

FIG. 137.—System, Wilson-Clyma, for the ventilation of carding rooms.

When the carding room is situated on an upper floor, the underground pit and air ducts must be replaced by metal conduits, the inside surfaces of which must be perfectly smooth.

The drawing off of the dust where generated and in a downward direction is the only really effective way of ventilating, and preventing the dust rising into the atmosphere of the room. The fan used with the above installation is that made by the Buffalo Forge Co., and is built on similar lines to the Sturtevant fan shown in figs. 140 and 141. These fans do not become obstructed by the waste, as do some centrifugal fans with closely-set blades.

*Huglo's System.*—Another system is that of Huglo, which may be thus described. Under each card is a pit about 18 inches deep. A fan is set in the front side of the pit under the feed sheet, the spindle of the fan being entirely covered to prevent the waste from lapping around it. The card is completely covered in, and the air to replace that removed by the fan enters at all the small apertures around the roller axles, etc., preventing the dust from issuing into the room. An endless sheet of wire netting, situated in the main duct and turned at a regular speed, separates the dust from the waste, the former being expelled into the outer air and the latter collected by hand.

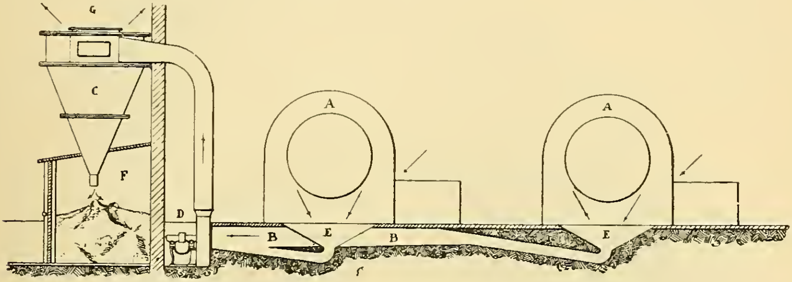

Fig. 138.—Section showing cards, conical pits, ducts, fan, cyclone and dust chamber for ventilation of carding rooms. System, Wilson-Clyma.

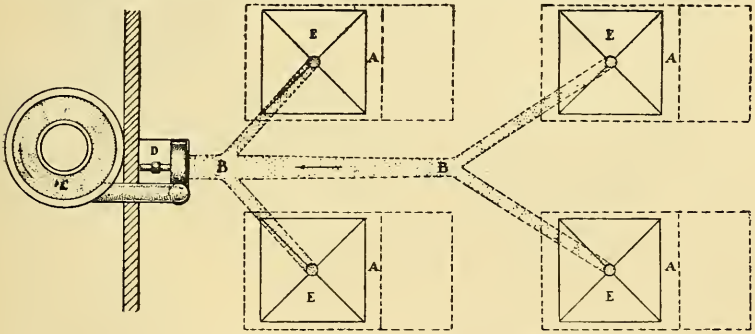

Fig. 139.—Ventilation of carding rooms. System, Wilson-Clyma.

*Carter's System.*—It is to avoid the laborious and unhealthy operation of the gathering up and baling of the card waste by hand, as also any danger of the removal of valuable fibre from the card cylinders by the action of a strong air current, that Carter's system of card-room ventilation and mechanical and automatic waste removal and baling shown in figs. 142, 143, 144, and 145 has been devised.

Fig. 142 is a plan of a carding room containing eight cards.

Fig. 143 is a vertical and longitudinal section of a row of four cards showing the main and secondary waste removal lattices, a waste balling chamber, and cyclone dust separator and depositer.

Fig. 144 is a vertical transverse section showing the main air duct and waste removal lattice directly under the row of cards.

Fig. 145 is a longitudinal vertical section showing the main duct and travelling lattice immediately under the row of cards, with the lattice rollers.

The arrangement shown in figs. 144 and 145 is to be preferred when the carding room is situated on an upper floor, as the duct required, being shallow, may be specially constructed and attached to the ceiling of the room underneath.

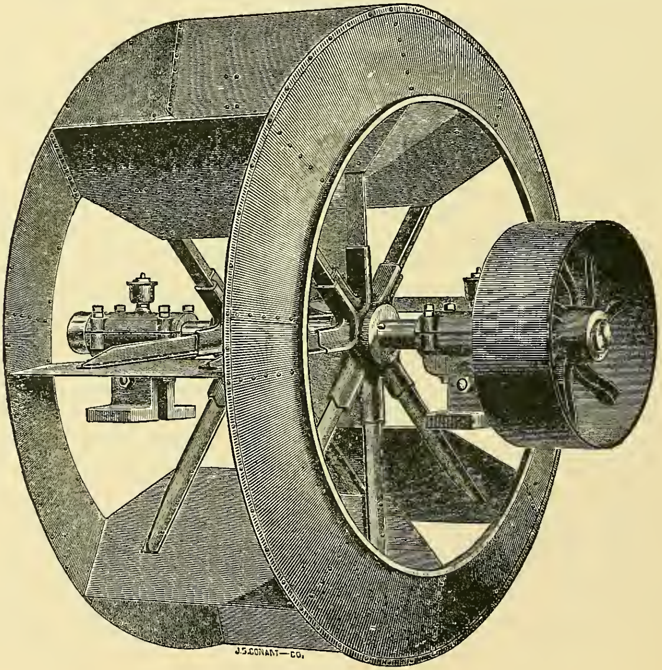

Fig. 140.—Fan wheel.

The apparatus is divided into two parts, one consisting of the fan or fans for the removal of the dust and of a cyclone depositer for causing the same to fall and accumulate in a sack or other receptacle, the other part consisting of travelling lattices to carry away the heavier waste and deposit it in bales or otherwise as desired.

The degree of draught may be reduced to a velocity just sufficient to carry away the light dust, leaving the heavier particles to be carried away mechanically. The travelling lattices may be driven either continuously or intermittently. If continuously, the quantity of waste remaining upon them at any time is so small as to cause an insignificant amount of damage in the case of fire. The travelling lattice may be of a fireproof material. The duct is of masonry, or, if on an upper floor, of sheet iron lined with fire tiles, and is also fireproof. Sprinklers may be placed in the upper portion of the duct, to come into operation on the outbreak of fire. The main lattice may be driven from one end by a belt and a series of

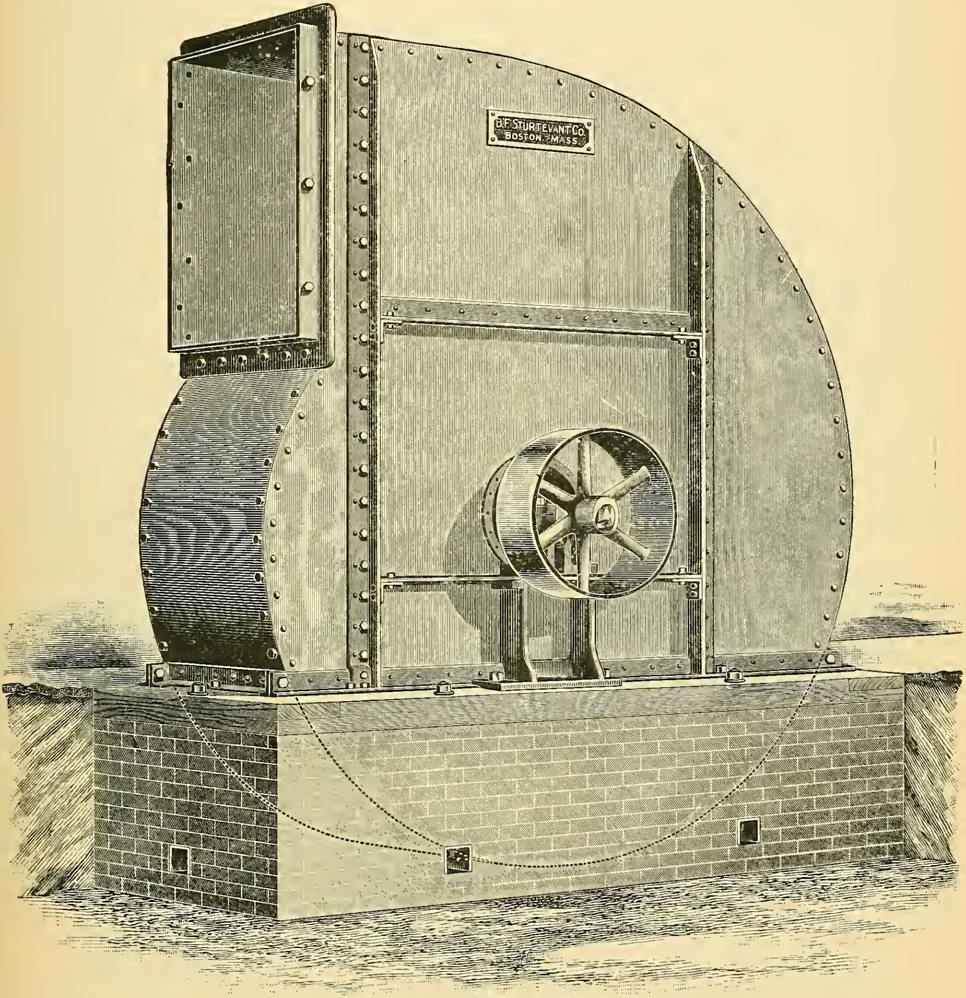

FIG. 141.—Sturtevant steel plate pulley fan.

wheels to give a slow speed. The secondary lattices, if employed, may be driven separately from their own card by a chain and sprocket wheel, or may communicate motion one to the other by means of spur or bevel gearing, etc. The openwork lattices serve as a sieve, the shove which falls through them, and is deposited in the bottom of the duct, being periodically removed by scrapers fastened when required upon the lattice, which may be turned in the reverse direction for a few minutes to scrape out the dust and shove. The iron framework supporting the lattices permits the hackle-setters to stand upon it, when they are occupied under the card, without doing any damage.

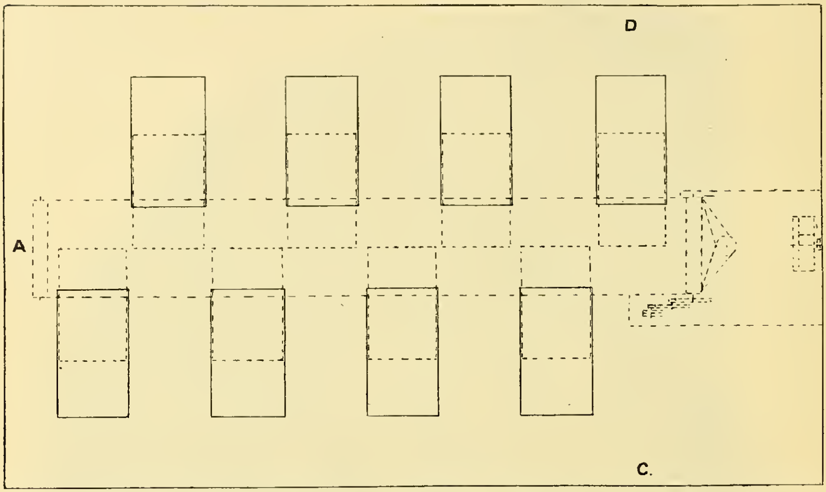

Fig. 142.—Plan of carding room fitted with Carter's ventilating and waste removal system.

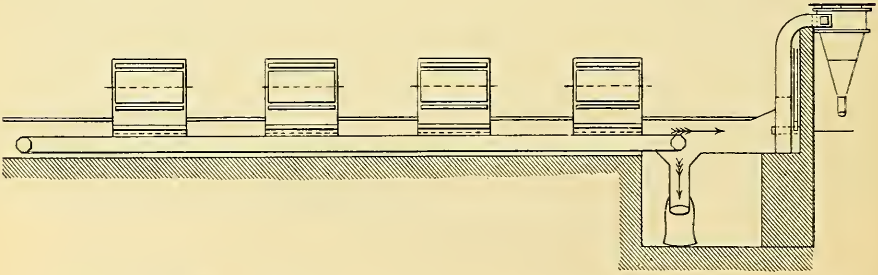

Fig. 143.—Longitudinal section of row of cards with air duct, travelling lattice, dust chambers and cyclone separator.

An inclined taper or bell-mouthed conductor or shoot, seen in fig. 143, is used to guide the waste into bales as it is delivered from the main travelling lattice.

The balling chamber, shown in figs. 142 and 143, is situated at the end of the main duct and travelling lattice. If on the ground floor, it is a cellar. If on an upper floor, it is a small outside building or a partitioned-off portion of the room beneath. Fig. 142 merely shows how a new and model room might be arranged. In old and existing rooms, the ducts and lattices must be arranged to suit circumstances. In every case the cards may be conveniently supported upon iron beams of **H** section, as shown in figs. 144 and 145, thus permitting the waste to fall directly upon the lattice underneath, which should be wider than the opening above it. When the card room is upstairs in a fireproof mill, the card should be placed in the centre of a bay and be supported upon auxiliary iron beams extending from one main girder beam to another, so that the building is not weakened in any way by the cutting away of the arch of masonry underneath the card. Supplementary lattices are used when the main lattice cannot be passed underneath the row of cards. Their duty is to convey the waste and deliver it upon the main lattice. The advantages claimed for this system are that, unlike some systems, the apparatus may be applied whether the carding room be upon the ground floor or upon an upper storey, or whatever may be the arrangement of the cards in the room, and that the installation requires very little power. If the secondary lattices are driven from the cards themselves, motion ceases when the card is stopped, and force is thereby saved. There is a complete ventilation and automatic removal of waste without an increase in the quantity of card waste

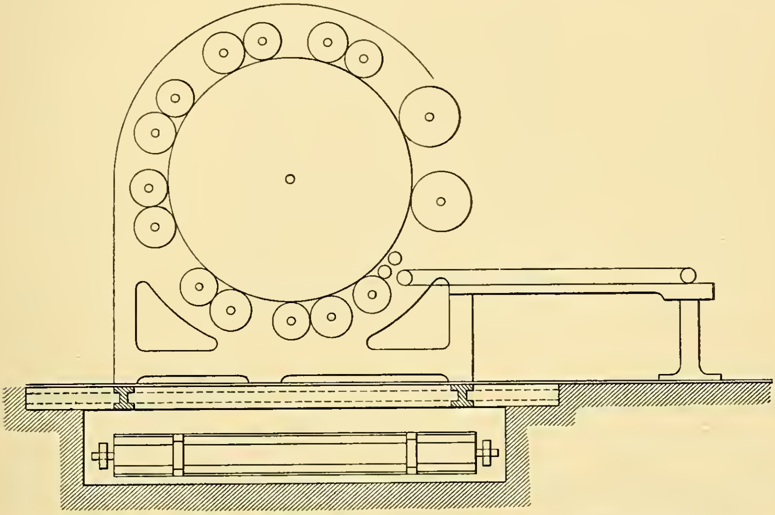

FIG. 144.—Transverse section through card, and air duct placed underneath. Carter's system.

produced; a saving in labour and a gain in health through avoidance of the necessity of removing the waste by hand and less damage in the case of fire, due to there being no accumulation of waste underneath the cards.

*Ventilation of Hackling Machines.*—Hackling machines are sometimes completely covered in and the dust which they generate drawn downwards through an orifice underneath into an air duct which is in communication with an extracting fan.

*Protection against Fire.*—Means should be provided to protect the mill buildings, stocks and plant against fire. So-called fireproof mills, built entirely of iron, bricks and mortar, are sometimes more damaged by fire than a mill in which wooden beams and columns are used, for the reason that wooden beams only char on the outside, the centre remaining solid, while iron beams and columns expand and twist with the heat, and often bring down the whole structure.

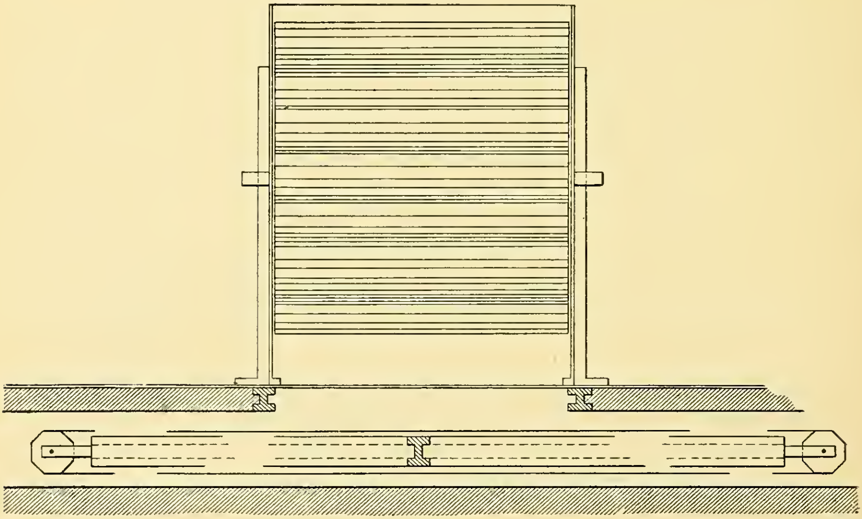

FIG. 145.—Longitudinal section through card, showing air duct, endless lattice and rollers. Carter's system.

Fire buckets should be provided in each room, as well as extinctors and hand grenades to be used at the moment of the outbreak. Automatic sprinklers are not so much used as they might be, considering their proved value in many an outbreak of fire. An installation of sprinklers consists in a system of piping attached to the ceiling and filled with water under pressure. The sprinkler nozzle is screwed into T's on the pipe, and is constructed in such a way that immediately the heat caused by the fire underneath becomes sufficiently strong, the solder which holds the nozzle closed melts and a copious shower of water is thrown down upon the fire.

A bell may be connected with the system, and arranged in such a way that it commences and continues to ring when a sprinkler opens work.

All important works should have a volunteer fire brigade, especially if the mill is situated in the country and out of reach of an official and properly equipped brigade. In forming this brigade the men of the place should be regularly trained in the use of a good hand pump and the proper management of the hose-pipe.

Every mill should have an outside iron stairway with doors opening outwards for use in case of fire. The rooms should be separated by iron doors, double if possible, and the separation walls should project through the roof.

# CHAPTER XX.

## BOILERS AND ENGINES, STEAM AND WATER POWER.

*Motive Power.*—In the linen trade, as in almost every other industry, steam, with the exception of water, which is not always available, affords the cheapest motive force. Gas engines have been tried for mill driving, and proved a failure, and electricity, as at present available, must be regarded rather as a means of transmitting motion than as a motive power. Flax spinning mills on the wet system could not, of course, do without steam in any case, as in the ordinary way the water in the spinning troughs must be heated to a considerable temperature, and steam is generally required for drying, especially in winter. Nevertheless, if a spinning mill be situated near to a water course, a great saving may be effected by utilising this natural source of power either to drive the whole mill or to supplement the force derived from a steam engine. In days gone by the breast wheel was the favourite form of water motor. To-day the turbine is almost universally employed both for high and low falls. Of the different types of turbines there is none better than the Samson turbine supplied by Messrs James Gordon & Co., London. Fig. 146 shows the turbine in its upright form. It consists of a runner or wheel formed of heavy flanged steel plates, cast into a strong centre piece which is keyed upon the vertical shaft, by means of which motion is conveyed to the machinery to be driven. A cast iron band surrounds the whole and gives the wheel strength and durability, and at the same time renders it proof against injury through contact with wood and other foreign substances which may drift down the river. Fig. 147 shows the same turbine mounted horizontally. This form is specially suitable for falls of from 8 to 15 feet, where it can be placed in an open trough, race, or flume, without any connecting pipes or casing. The horizontal driving shaft may be conveniently extended through a stuffing box and gland in the side of the flume, and a belt or rope pulley mounted thereon. The water enters the turbine from the outside, passes through it, and is discharged through the draught tube seen to the right of the figure. Fig. 148 is a similar turbine fitted with a rope pulley and cased in, being fed with water through the supply pipe shown. Double the power may be obtained from a double turbine constructed on this principle, consisting of two wheels mounted in the same case and upon the same horizontal shaft as shown in fig. 149.

Turbines may be used whenever a 3 to 3000 feet head of water is at hand. To ascertain the power available, the first step is to measure the amount of head or fall. This is most conveniently done by means of an engineer's level, which is run from a point at the upper line of water rights to a point at the lower line of rights. The vertical distance between these two points is the head or fall. The next step is to ascertain the quantity of water which the stream affords. This can be done by estimating the cross section of the stream in square feet and multiplying by the velocity in feet per minute, the result being the cubic feet of water passed per minute. This calculation is rendered easier by the construction of a weir, say out of a plank, and then measuring the depth of water which passes over it. This depth in feet multiplied by the width of the stream in feet gives the section in square feet. The average velocity of the current may be estimated by throwing a floating body into the stream at that place and timing it over a measured distance. The velocity of the water on the surface and in the middle of the stream will always be higher than it is near the edges and bottom, since there is friction

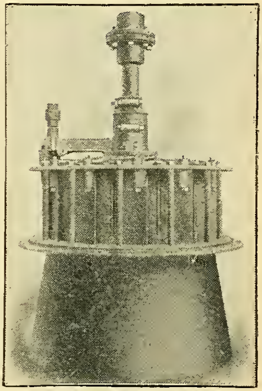

Fig. 146.—Upright Samson turbine. Supplied by Messrs James Gordon & Co., London.

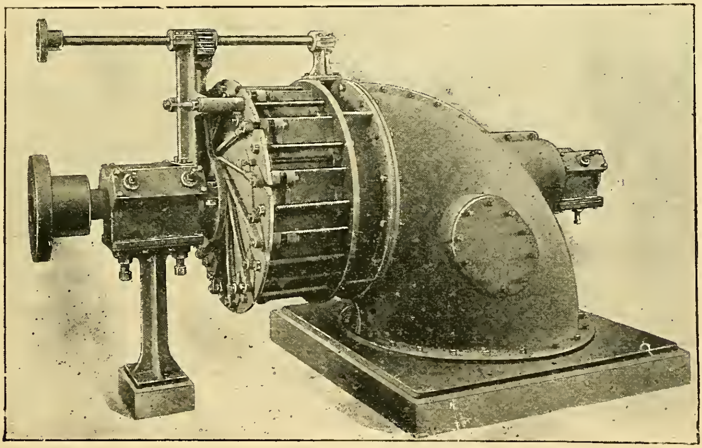

Fig. 147.—Horizontal Samson turbine.
Supplied by Messrs James Gordon & Co., London.

between the moving body of water and the sides and bottom of the stream, so that the velocity obtained will probably be rather over the mark. The weight of a cubic foot of water is about 62 lbs. The theoretical power available is the product of the weight of water which passes per minute, and the height or head through which it falls, divided by 33,000, the number of foot pounds which constitute a horse-power. The actual power which may be taken off is the product of the theoretical power and the efficiency of the water motor employed.

The efficiency of the types shown is about 80 per cent., which compares very favourably with that of other forms of water motors.

Before leaving the subject of turbines, we must mention that steam turbines are already on trial in textile mills, and may, before the end of the century, displace the use of the steam engine to some extent. Their possible greater efficiency lies in the fact that, running constantly in the same direction, there are no moving parts to be brought to rest at repeated intervals, as there are in the steam engine at each stroke of the piston.

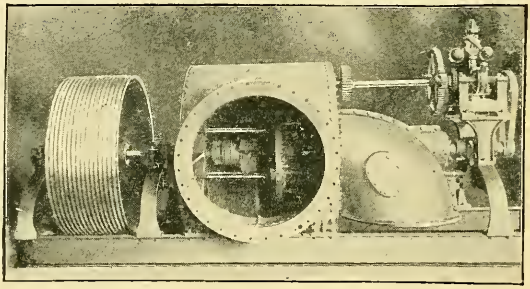

FIG. 148.—Horizontal Samson cased turbine. Supplied by Messrs James Gordon & Co., London.

An important installation of steam turbines has just been made by the British Westinghouse Manufacturing Co., Ltd., in the large jute mill of Messrs Birkmyre Bros., on the river Hugli, near Calcutta. The turbines are of the multiple expansion parallel flow type, running at 1500 revolutions per minute with steam at 175 lbs. pressure per square inch, 200° F. superheat, and a 27½-inch vacuum. Each turbine exhausts into a vertical surface condenser having 4800 square feet of cooling surface.

*Boilers.*—Turning to the subject of steam, the boilers must first occupy our attention. In British flax, hemp, and jute mills, the Lancashire and Cornish types of boilers are almost universally employed, the number of the former exceeding that of the latter. Some few water-tube boilers of the Babcock & Wilcox type are likewise used, as they are also on the Continent.

In the north of France an externally-fired compound cylindrical boiler (shown in section in fig. 150) is a very favourite type. It is composed of three or more cylindrical shells, 3 to 4 feet in diameter, united one to the other by communicating tubes through which a man can just pass.

This boiler gives a large heating surface and is of large capacity, and easily cleaned, as there are no narrow and confined spaces as in a Lancashire boiler. Fig. 151 shows a Lancashire boiler of modern type. This boiler has, in common with the Cornish type, a large cylindrical body 18 to 30 feet in length, pierced from end to end, in the former type with two, in the latter type with one, cylindrical flue, in the front end of which the fire-grate is situated. The material used should be the best steel plate for high pressures, or the best Thornycroft or Staffordshire rolled plate for medium pressures. The front rings of the flue, upon which the fire impinges most, should be of the very best Low Moor or Bowling iron plate. For a Lancashire boiler, 30 feet long by 7 feet 6 inches diameter, to work at 150 lbs. pressure per square inch, the shell plates should be $\frac{3}{4}$ inch thick, and the longitudinal joints double-butt strapped and trebly riveted. For a similar boiler, to work at 100 lbs. steam pressure, half inch will be found a sufficient thickness for the shell plates, the longitudinal seams being double lap-jointed.

The indicated horse-power which can be supplied by a boiler of this type may be based on a coal consumption of 24 lbs. per square foot of grate area per hour, an evaporation of $8\frac{1}{2}$ lbs. of water per lb. of coal, and a water consumption of 18 lbs. per I.H.P. per hour for a compound Corliss condensing engine, and 23 lbs. per I.H.P. per hour for the simple Corliss condensing engine. Twenty-four lbs. of coal per square foot

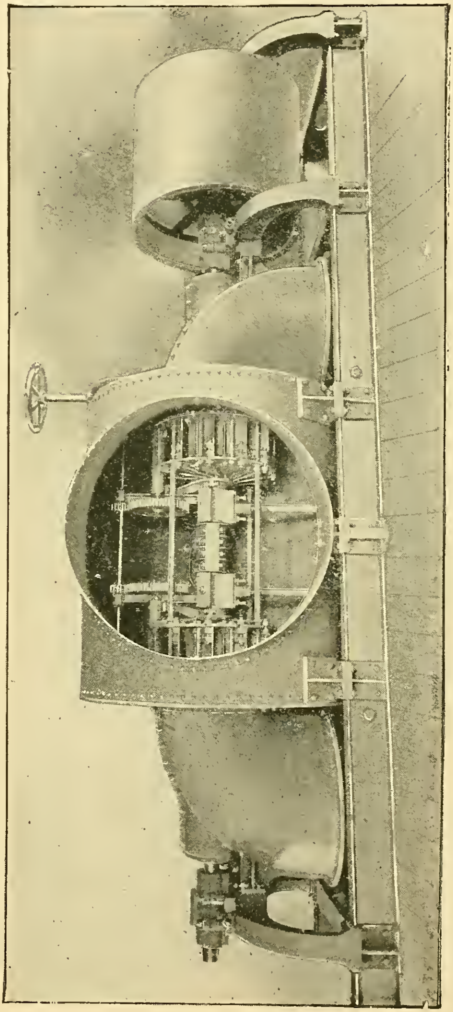

Fig. 149.—Double horizontal cased Samson turbine. Supplied by Messrs James Gordon & Co., London.

of grate area per hour should be easily consumed with an ordinary draught, and $8\frac{1}{2}$ lbs. of water, at an initial temperature of 25° F., evaporated per lb. of coal consumed. The flue plates may be the same thickness as the shell, or $\frac{1}{16}$ inch lighter, but the end plates should be $\frac{1}{8}$ inch heavier. The end plates are secured to the shell by means of angle iron and stayed by gusset plates secured by double angle irons. These gusset angle irons should never approach within 10 inches of the flue, in order that "grooving" may be avoided by giving elasticity to the end plate. Grooving is the weakening effect produced by the repeated bending backward and forward of a plate at a point where it is rigidly held, and in the end plate of a Lancashire or Cornish boiler is produced by the expansion and contraction of the flues which unite the end plates. The flues should be built up in sections, united by Adamson's flanged seam or expansion joint, and are often intersected by four or more Galloway tubes welded in. The use of Galloway tubes is now, we believe, being discontinued by some of the best makers. The manhole mouthpiece should be of wrought iron or steel double riveted to the shell of the boiler. The rivet holes should be drilled in position and never punched. Two longitudinal stay bolts usually pass through the boiler from one end to the other in order to strengthen the end plates, but should always remain slack to avoid grooving. The fire bars should rest on bearers riveted to the furnace plates. Numerous systems of moving fire bars, mechanical stokers, and force draughts have been devised, the most successful of the latter being probably the Meldrum system, in which the air is drawn into a closed ashpit by means of a special steam jet blower and forced through the fire on the grate. A very much poorer fuel may be burned successfully by the use of the Meldrum furnace. The steam is usually taken from Cornish and Lancashire boilers by means of an anti-priming pipe, but the use of steam domes or a collector is much to be preferred to supply the engine

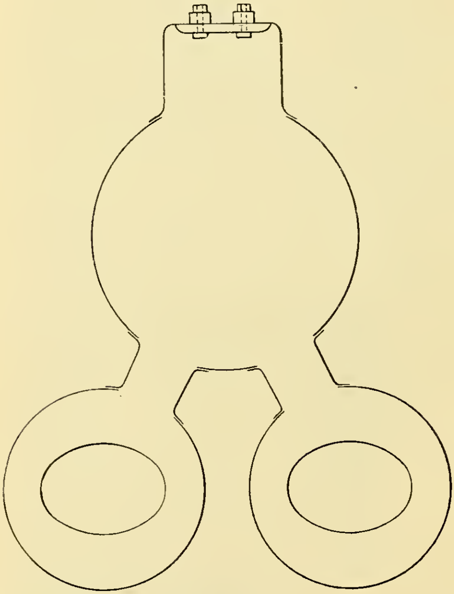

Fig. 150.—Section through a French generateur à bouilleurs.

with dry steam. The length of Lancashire boilers runs from 21 to 30 feet. The grate surface is from 25 to 39 square feet, the effective heating surface from 490 to 900 square feet, and the power from 280 to 440 I.H.P., according to size, with a good engine.

The Babcock & Wilcox boiler is a water-tube boiler with a cylindrical body, which is placed rather high up. The tubes are about 4 inches in diameter, are outside the body of the boiler, and extend in a slanting direction from front to back over the furnace, the flame and gases from which pass upwards through them over a high bridge and downwards through them again to the flue. With this class of boiler steam pressure

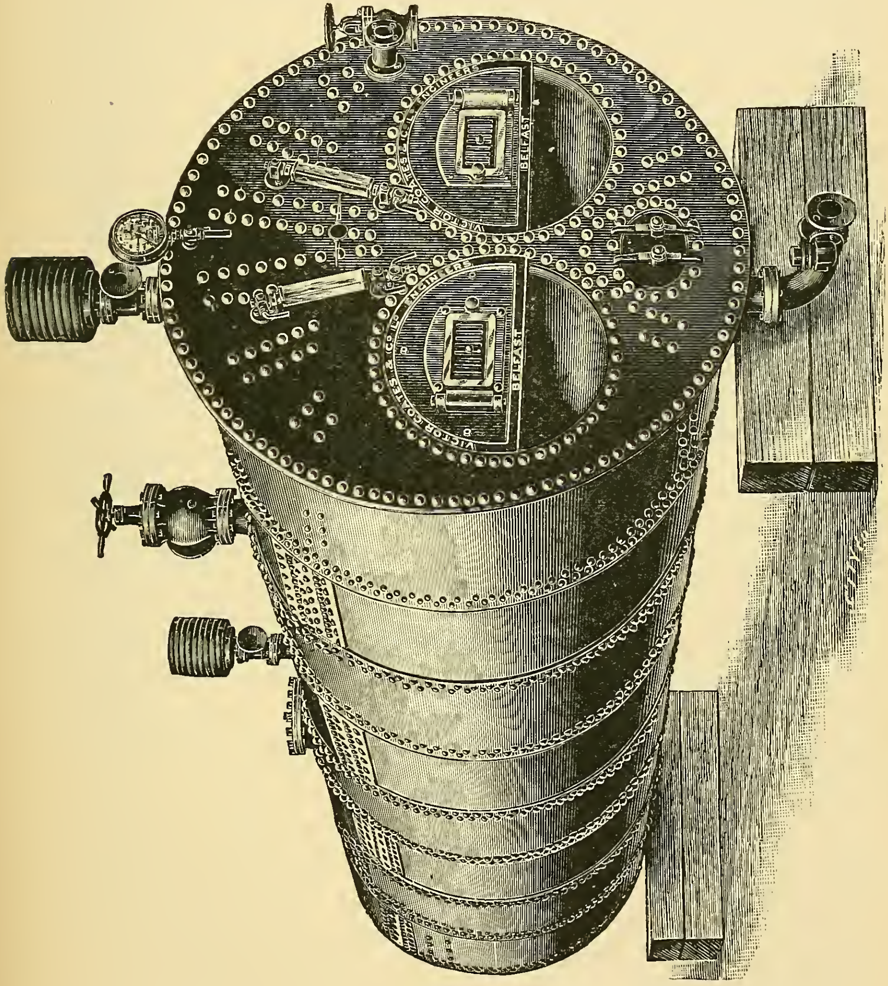

Fig. 151.—Lancashire boiler, as made by Messrs Victor Coates & Co., Ltd., Belfast.

may be quickly raised, but falls equally quickly. For wet spinning mill work, where a store of steam is often required during the night for drying, etc., a boiler with more steam space is to be preferred. With hard or dirty water, water-tube boilers are often troublesome, from the fact that the tubes become choked and have often to be almost bored out, notwithstanding the fact that a mud-cock is provided and the sludge blown off daily. In water-tube boilers the furnace doors should be on the swinging principle, and arranged in such a way that if a tube should burst, the pressure of water and steam puts out the fire and holds the furnace door shut, to the protection of the firemen.

The setting of steam boilers is an important point, as the flues must be easily accessible for cleaning and for the examination of the boiler shell. In Lancashire and Cornish boilers the smoke, flames, and hot gases should, after leaving the internal flue or flues, pass into an external flue passing under the bottom of the boiler from back to front. At the front end of the boiler the gases are split into two parts, one part entering a side flue to the right and another part a similar flue passing along the left side of the boiler. At the back end of the boiler these flues communicate with the main flue leading through the economiser to the chimney. The two side walls of the bottom flue upon which the boiler rests should be as narrow as possible, in order to leave a large surface, and especially the longitudinal seams, uncovered. Fireclay is the material which must be used in the construction of the flues, the boiler resting on specially-shaped blocks of that material, the side flues covered with fireclay tiles, and the use of lime mortar carefully avoided. The blow-off or mud-cock being in the front bottom portion of the boiler, the latter should have an inclination of about 2 inches from front to back, in order to run the boiler completely dry for cleaning, etc. The bottom flue should be about 30 inches wide for a 5-foot boiler and 54 inches wide for an 8-foot boiler, its depth varying likewise from 24 to 30 inches. The narrowest part of the side flues should not be less than 12 inches. As regards height, the side flues should always extend above the top of the furnace crowns.

An apparatus known as an economiser should be inserted in the main flue between the boilers and the chimney. Its object is to utilise the large quantity of heat still possessed by the smoke and gases, in raising the temperature of the feed water. The gases from the boilers usually enter the main flue at a temperature of 400° to 700° F., and may be robbed of their heat to the extent of raising the feed water from a temperature of about 90° to 300° F. in extreme cases. When the feed water has a lower initial temperature than 90° F., which rarely occurs if water from the hot well of the engine be used, its passage into the economiser pipes sets up a most injurious "sweating" or condensation on the exterior surfaces of the tubes, causing rapid corrosion and caking of the soot. If the engine has a condenser, water is, as we say, easily obtainable at a sufficient temperature from the hot well. When the engine is on the non-condensing principle, the exhaust steam may be conveniently used to heat the feed water to a temperature at which it may with safety be passed to the economiser. Practically the only economisers in use are Green's and Locock's, which, to all intents and purposes, are the same. The cast iron pipes through which the feed water is circulated, and which offer the large heating surface required, are arranged vertically, in rows of from four to ten pipes, in a chamber forming part of the main flue, which is thus 40 to 90 inches wide at this point. The number of pipes which may be advantageously employed may be estimated at the rate of one pipe for every 3 I.H.P. developed by the engine. Thus a mill utilising 600 I.H.P. should have a battery of $\frac{600}{3} = 200$ economiser pipes. Satisfactory results may also be obtained by allowing four pipes to every ton of coal burnt per week.

The smoke in passing among the tubes deposits a large quantity of soot upon them, which soot, if not scraped off, would act as a non-conductor and prevent the absorption of heat. Scrapers have consequently to be employed to keep the outside surface of the tubes free from soot. These scrapers, which embrace the tubes, are given a slow but constant reciprocating up-and-down motion by means of chains, balance weights, and motive force, provided by a belt or electric motor. The soot as scraped off accumulates in a chamber underneath the apparatus, from which it is periodically removed. Should the scrapers become clogged at any time through the presence of humidity on the tubes, the economiser should be run dry, the hot gases left circulating among the tubes, and the scrapers kept going until the soot is burnt away and they work easily again. Care must be taken that the tubes are cold before water is again admitted, lest an accident should happen through a rapid rise in pressure. A safety valve should always be provided to minimise danger on that score. A reserve or alternative flue passes underneath the economiser, so that by the use of dampers the apparatus may be stopped for cleaning or repairs. If the economiser is much exposed it is advisable to empty it prior to a prolonged stoppage in frosty weather. The pipes are forced into taper sockets in the top and bottom boxes. Openings in the upper box opposite each pipe are closed by ground and taper cast iron stoppers or "lids." It is sometimes a little bit difficult to make these stoppers watertight when they are replaced after cleaning. The best way is to smear the faces with a little white lead and draw up the lid very tightly with a T-headed bolt and bridge piece, tapping around the hole all the while with a hammer. The use of red lead, and sometimes even of a very thin sheet of the metal lead, may have to be resorted to in extreme cases. A blow-off or mud-cock is provided, and should be blown off regularly every day, as, even with comparatively soft water, the tubes are apt to become choked by sediment and incrustation. A thorough cleaning should be made at least once a year, it being found necessary in some cases to actually bore out the tubes, so completely are they filled with a calcareous deposit.

The prevention of incrustation on the internal surfaces of the boiler and of the economiser tubes is a matter of the very greatest importance, both as regards economy of fuel and durability of the boiler. Deposit of this sort prevents the passage of heat to the water, and is apt, especially in the case of the furnace plates, with which the flames come into actual contact, to cause overheating, burning, and injury. Incrustation is due to the presence in the feed water of salts of lime, magnesia, etc., which can only be removed by chemical means, necessitating the use of a water-purifying apparatus.

*Water Testing and Purifying.*—The presence of lime in the feed water may be detected by mixing with it a soap solution, when, if present, an insoluble lime compound in the form of a thick curd will form after sufficient soap has been added to neutralise the lime. In order to detect the presence of lime as carbonate or sulphate, the water is evaporated to one-eighth of its bulk. If the water remains clear it may be taken as a sign that lime is either absent altogether or present in the form of nitrate or chloride. Usually, however, the water becomes turbid, in which case add a little hydrochloric acid and watch the effect. If the liquid effervesces and becomes clear, the water contains carbonate of lime; on the contrary, if no effervescence takes place, it is sulphate of lime which is present: if it effervesces and partially clears, both carbonate and sulphate of lime are dissolved in the water.

Lime may also be detected by the addition of a solution of ammonium oxalate to the water in question. If lime be present a white precipitate of calcium oxalate is formed. When this precipitate has been removed by filtering, the presence of magnesia may be detected by concentrating the liquid by evaporation and mixing with it a solution of phosphate of soda and ammonia. If a white crystalline precipitate is thereby produced, it may be assumed that magnesia is present.

Bicarbonate of lime is easily detected by merely boiling the water or adding to it a clear solution of lime water. In both cases the lime falls as a white precipitate.

The precipitation of lime by the addition of lime water is the discovery of a certain Dr Clarke, and forms the basis of all systems of water softening and softeners.

The theory of Dr Clarke's process of purification and softening with lime is as follows:—Since calcium and magnesium carbonates are only soluble in water containing carbonic acid which it has extracted from the air, etc., the natural remedy is to employ some means which will rapidly and effectually absorb this acid. Dr Clarke used calcium hydrate or slaked lime as the cheapest and most suitable agent for this purpose, and it is this material which is in general use to-day. The following equation expresses the theory of the process:—

$$\mathrm{CaH(Co_3)_2} + \mathrm{Ca(OH_2)} = \mathrm{2CaCo_3} + \mathrm{H_2O}.$$

$$\begin{array}{c}\text{Calcium}\\ \text{Bicarbonate}\end{array} + \begin{array}{c}\text{Calcium}\\ \text{Hydrate}\end{array} = \begin{array}{c}\text{Calcium}\\ \text{Carbonate}\end{array} + \text{Water.}$$

Only the temporary hardness is thus removed, and not even completely. It is best to use clear lime water for correction, because it possesses a known constant composition. The amount of such lime water which it is necessary to employ may be calculated after making an analysis of the water, or it may be found by actual experience. The addition of too much lime water must be avoided, and is readily detected by adding a few drops of a filtered decoction of cochineal to a small quantity of the water being treated. Excess of lime water changes the yellowish-red colour of the solution to a violet. A small quantity of caustic soda may also be conveniently added to the feed water to be purified, as, besides aiding in the precipitation of the lime, it forms sodium carbonate, which decomposes any sulphate of calcium or magnesia which may be present. The construction of an improved apparatus for employing Clarke's process upon boiler feed water is as follows:—The water to be purified is allowed to flow in regular quantities into the enlarged open end of a large vertical pipe, into which flow at the same time the necessary quantities of lime water and soda lye. The feed water is thus at the first intimately mixed with these re-agents and passes into the lower portion of the depositing tank—a large rectangular receptacle, the lower portion of which is divided up by a series of diaphragms or plates riveted on to the sides at an angle of 45°. The action of the lime water and soda lye is, as we explained, to precipitate the lime held in solution. The lower end of the vertical pipe just referred to is provided with a mud-cock, by means of which the pipe should be regularly purged of any accumulation of precipitated lime. The object of the diaphragms in the depositing tank is to split up the water into thin layers and to provide a large surface for precipitation. The diaphragms are inclined so that the lime may run to the side, where it accumulates, to be periodically run off by purge cocks. Rising upwards the water passes through a filter of sponges or wood shavings held in trays, and then flows off to the tank from which the boiler feed pump is supplied. The purified water should be regularly tested to see that lime water and soda are being employed in proper proportions. To do this, measure 100 cubic centimetres of purified water into a bottle, and then measure in gradually a standard soap solution by means of a burette or pipette graduated in cubic centimetres. After each addition of soap solution, shake the bottle and note the point when a froth or lather is formed which will last for at least five minutes. If a great deal of soap is used in forming this lather, it may be taken that the water is still hard with dissolved lime. The standard soap solution referred to may be prepared by dissolving 10 grammes of Castile soap (60 per cent. olive oil) in 1 litre of weak alcohol. Such a solution contains exactly enough soap in 1 cubic centimetre to precipitate 1 milligramme of carbonate of lime. The alcohol should be about 35 per cent. strength.

Some other forms of water purifiers which are modifications of Clarke's apparatus and process are: Porter Clarke's, Gaillet Huet's, the "Stanhope Purifier," Lemaire's, the "Tyack Softener," the Slack and Brownlow Purifier, and the Archbutt-Deeling Purifier, etc.

Instead of purifying the feed water some people take steps to keep the deposit, left by the water as it evaporates, in a soft state or in the form of mud, and thus prevent the formation of a hard and injurious scale. The accumulation of mud may be blown off occasionally through the mud-cock and the boiler thus worked for a considerable time without cleaning. A sack of potatoes put into the boiler after cleaning is often used to produce this result, as is also sometimes the injection of given quantities of petroleum, barium (pure or in the form of aluminate), etc. The admission of oil, in any form, into the boiler is not to be advocated however, since it tends to induce priming or the passage of water with the steam to the engine. Some patent acid scale removers have a good effect in causing scale to fall or to prevent its formation. Due care must, however, be taken that the boiler plates are not attacked. With certain waters an admixture of caustic soda with the feed water has a good result, but if too much be employed it will exercise a most injurious effect on the brass boiler fittings, especially where there is already a small leakage. Some impure feed waters tend to corrode the internal surface of the boiler.

The suspension of a piece of zinc under the surface of the water in the boiler has a protective effect, since the zinc is first attacked and oxidised, when it swells up into a spongy mass. The zinc is more effective if it be connected with the boiler plates by a metallic conductor.

*Feeding Boilers.*—Boilers under pressure are generally supplied with water by means of the feed pump of the engine, which may draw its supply from the hot well, from a tank of softened and purified water, or from other supply. The water is turned on to the pump when required by the boilers, the feed valves of the latter having previously been left open. It is very convenient to have a small independent feed pump for use always, even when the main engine is stopped. If such a pump be not at hand, the only way of feeding boilers under pressure when no pump is available is by means of water under a sufficient head, which is seldom to be obtained, or by means of an apparatus known as Giffard's injector. The theory and construction of the injector is as follows:—Steam from the boiler is admitted into the steam chamber of the injector, from which it is allowed to rush out through an adjustable narrow aperture into the water chamber connected with the water supply. The steam rushing out in a jet at high velocity pushes before it a small column of water, to which it gives the same high velocity and sufficient momentum to force open the conical check valve which separates the feed pipe from the boiler. Thus, contrary to what might be supposed, steam under a given pressure is able to force water into a boiler under the same pressure.

If the drain pipe from a series of heating pipes, such as those of the drying loft, for instance, be connected with the boilers through a check valve, the condensed steam or water there produced will flow naturally back into the boilers if there be at least a 10-foot head in order to increase the back pressure sufficiently to lift the valve. The feed water should enter the boiler under the water level and towards the rear, in such a way that the perhaps cold water does not impinge on the plates directly heated by the fire. The head of water necessary to feed the boiler under pressure may be calculated from the fact that a column of water 1 foot high and of 1 square inch sectional area weighs ·4 lb. Hence to feed a boiler under 60 lbs. steam pressure requires a head of over $\frac{60}{\cdot 4} = 150$ feet.

*Pressure Gauges.*—Every steam boiler must be furnished with several safety appliances to avoid accidents. These should consist of one or more indicators to show the height of the water in the boiler, two safety valves, and a steam pressure gauge. All surfaces exposed on one side to the heat of the fire should be covered with water on the other. In Cornish and Lancashire boilers the furnace crowns should be well covered. Should they be left uncovered, the crown might become red-hot and cause the collapse of the flue, or, if water should unfortunately be admitted while they are in that condition, an explosion due to the too rapid generation and rise in pressure of the steam. The ordinary water gauge has a vertical gauge glass, the upper end of which is in communication with the steam space of the boiler while the lower end communicates with the water space. Both connections being open, the water rises in the tube to the same level as it is in the boiler, which is thus clearly seen. The gauge cocks should be opened and shut frequently and the tube purged, to avoid the possibility of its not acting as it should owing to deposit in any of its connections. Both steam and water inlets should be closed by ball valves, which cut off the supply automatically when a gauge glass breaks and the pressure becomes unbalanced. Besides the gauge glass, it is advisable to have a water level gauge, actuated by a float attached to a rod passing up through the top of the boiler, and carrying or actuating an index finger by means of a rack and pinion. The rod may, furthermore, be provided with projections, which, in certain positions, act upon valves and admit steam to sound low and high-water whistles. An ingenious method of causing this class of indicator to show the water level is to fix a magnet on the upright rod moving in a steam-tight envelope This magnet causes a light piece of steel tube to move up and down over the face of a graduated scale which is open to the air, and thus to indicate the water level. All pressure gauges in general use are constructed upon the Bourdon principle, which consists in the use of a closed copper pipe, bent round into almost circular form. The end communicating with the boiler is fixed, while the closed end is free, and is connected with an index hand, which moves over a graduated scale according as the steam pressure causes the curved tube to straighten itself out.

In England steam pressure is denoted in lbs. per square inch, while on the Continent it is spoken of in terms of kilogrammes per centimetre carré (square), or sometimes in atmospheres. Below we give a table showing the equivalents under the three systems.

| Kilogrammes per centimetre carré. | Pounds per square inch. | Atmospheres. | Pounds per square inch. |
|---|---|---|---|
| 1 | 14·22 | 1 | 14·7 |
| 2 | 28·45 | 2 | 29·4 |
| 3 | 42·67 | 3 | 44·1 |
| 4 | 56·89 | 4 | 58·8 |
| 5 | 71·11 | 5 | 73·5 |
| 6 | 85·34 | 6 | 88·2 |
| 7 | 99·56 | 7 | 102·9 |
| 8 | 113·78 | 8 | 117·6 |
| 9 | 128·01 | 9 | 132·3 |
| 10 | 142·23 | 10 | 147·0 |

Safety valves are either weighted by a dead weight or by a lever and weight. Those shown upon the top of the Lancashire boiler (fig. 151) are of the dead weight type. When a lever is used, its length should be such that the desired pressure is maintained when the weight is on the extremity of the lever, rendering it impossible for the weight on the valve to be augmented, either intentionally or by inadvertence. It is prudent to have a safety valve, as well as a water level gauge, of each sort, on every boiler. The area in square inches of the safety valve required by the Board of Trade for a boiler may be found by multiplying the square feet of fire-grate surface by 0·326 for a boiler working at 100 lbs. pressure per square inch, and by 0·375 for those working at 85 lbs. pressure. Thus a 7 foot 6 inch by 21 foot boiler with 30 square feet of grate surface will require a safety valve of $30 \times 0{\cdot}326 = 9{\cdot}78$ square inches when working at 100 lbs. pressure per square inch, and a larger valve of $30 \times 0{\cdot}375 = 11{\cdot}25$ square inches area if working at only 85 lbs. pressure. If the lift of the valve be equal to one-fourth part of its diameter, that lift will be sufficient to pass the maximum amount of steam which can possibly escape. The pressure per square inch which may be maintained by a lever of given length and weight upon which a ball of given weight is hung may be calculated from the following formula :—

$$P = \frac{WL}{AF} + \frac{w \times g}{AF} + \frac{v}{A}, \text{ where}$$

P = pressure in lbs. at which the valve will blow.
W = weight of the ball on the lever in pounds.
L = length of the lever from the fulcrum to the weight, in inches.
A = area of the valve in inches.
F = length from the fulcrum of the lever to the valve spindle, in inches.
$w$ = the weight of the lever itself.
$g$ = the length from the fulcrum to the centre of gravity of the lever.
$v$ = weight of the valve and spindle.

To find the weight W, which must be used to sustain a given steam pressure, the formula

$$W = \frac{AF\left\{P - \left(\frac{w \times g}{AF} + \frac{v}{A}\right)\right\}}{L} \text{ must be used.}$$

To find the distance L from the fulcrum at which to place the weight to sustain a given pressure, use the formula

$$L = \frac{AF\left\{P - \left(\frac{w \times g}{AF} + \frac{v}{A}\right)\right\}}{W}.$$

*Firing the Boiler.*—The manner of firing the boiler is of the greatest importance as regards the consumption of coal or the amount of water which can be evaporated by or power which can be obtained by burning one pound of fuel. The coal must be spread evenly and in a rather thin layer over the surface of the firegrate. The damper should be almost closed before opening the door for firing, in order to minimise cooling by an inrush of cold air. The clinker must be broken up with the slice bar, and the fire cleaned as frequently as required by the quality of the coal. The feed of water should be as regular and constant as possible in order that full advantage may be taken of the economiser. The steam pressure should be maintained at the regulation pressure for the boiler and engine, for to work at a lower pressure means a larger coal consumption for the same work, since high pressure steam is more economical from the fact that fewer thermal units are required to raise steam at a high pressure to a pressure 1 lb. per square inch higher, than are required to raise the pressure of low pressure steam by the same amount.

It is this physical law which leads up to the use of superheaters for dry steam, a principle which has already been adopted and is likely to grow in favour as the century grows older.

The firebars are usually of cast iron, but occasionally of rolled wrought iron. The space between the bars varies from $\frac{2}{5}$ inch to $\frac{1}{4}$ inch, according to the size of the fuel being used. Thin bars have the advantage of causing the air to be better split up in passing through the red-hot fuel. The bars will be kept cooler and last longer if the ash-pit be constructed in such a way that it may be kept full of water.

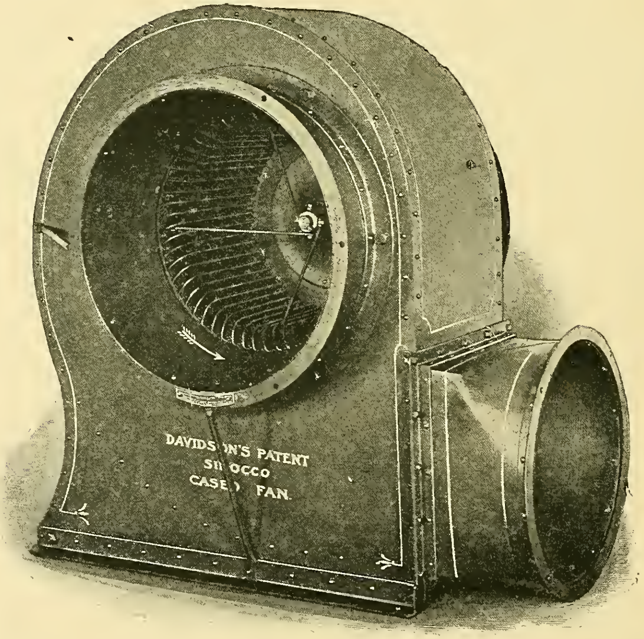

Fig. 152.—Davidson's Sirocco fan,
as supplied by Messrs White, Child & Beney, Ltd., London.

The draught obtainable by the use of a chimney rarely exceeds 1·1 inch of water, and is due to the difference in weight of the column of hot air contained in the chimney and that of a similar column of the outside air, consequently the diameter of the chimney has a much greater influence on the draught than has the height.

Within recent years high chimneys have been replaced in some instances by centrifugal or turbine fans of the Sirocco or Sturtevant type. A Sirocco fan is shown in figs. 152 and 153, while we showed the Sturtevant type in Chapter XIX. by figs. 140 and 141. The air may be either propelled or drawn through the fire-grate, and the speed of the fan may be regulated to give the quantity of air required at any time to burn the smoke, etc. If properly applied, as shown in fig. 153, good results may be obtained, the force absorbed in driving the fans not exceeding the equivalent of $\frac{1}{2}$ per cent. of the coal consumed.

*Steam Pipes.*—Steam pipes of cast iron may be used for low pressures, but for high pressures they should be of copper, riveted steel plate, or electrically-welded wrought iron. If the pipes are long, expansion joints should be used. The pipes should be given a fall towards the boiler to run off condensing water, and should be covered with a non-conducting composition, such as fossil-meal or asbestos rope.

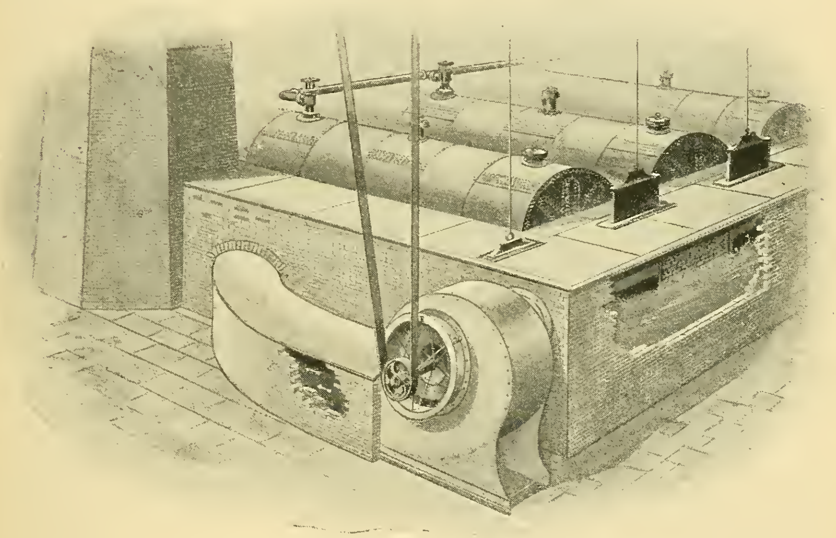

FIG. 153.—Induced draught produced by a Sirocco fan.

*Steam Engine.*—No spinning mill or rope works can be considered up to date, or, indeed, be really economically worked, without a modern type of engine. The compound or triple-expansion horizontal engine is the one most generally employed, although in the Irish industrial capital a type known as the inverted cylinder vertical triple-expansion condensing engine has been very extensively and successfully adopted. A very good example of such an engine is that constructed by Messrs Victor Coates & Co., Ltd., Belfast, and driving such mills as that of the Brookfield Linen Co., Ltd., Belfast. This engine has three cylinders—19 inches, 29 inches, and 46 inches in diameter respectively, each having a stroke of 4 feet, and indicates 1000 horse-power when running at 75 revolutions per minute, with a boiler pressure of 160 lbs. per square inch. Each of the three cylinders is supplied with four Corliss valves—two for steam admission and two for exhaust. In this particular engine the steam admission valves are fitted with Dobson's patent cut-off gear, which is controlled by a quick-speed governor in order to render the speed still more regular. The cylinders are arranged in regular succession—high pressure, intermediate, and low pressure—and have the Corliss valves placed at right angles to the crank-shaft, instead of parallel to it, as is often the case. The three cylinders are bolted together, and receivers thus formed between first and second and second and third respectively, connecting steam pipes being thus dispensed with. The piston rods are fitted with United States metallic packing, and the Corliss valve spindles arranged so that no packing is necessary. The piston heads are supplied with Rowan's patent rings. The cylinders are supported by columns resting on the bedplate, which carries the crank-shaft in six bearings. The crank-shaft is made of steel, built up of thirteen pieces carefully shrunk together and turned up. The fly-wheel, supported in two special bearings, is 15 feet in diameter, and has 30 grooves for 1¾-inch cotton ropes. The air pump is worked by levers from the intermediate cylinder, and has a force pump at either side. A convenient "barring engine" is supplied for putting on ropes, etc., while white-metal is used for all the bearings.

As an example of another leading type of mill engine, and in order to show that Continental engineers have little to learn from us, we will briefly describe a large horizontal triple-expansion mill engine built by the Chemnitzchauer Maschinenfabrik, Saxony. This engine, which indicates 2000 horse-power, when running at 65 revolutions per minute and supplied with steam at 180 lbs. pressure per square inch, has four cylinders—a high-pressure cylinder 24½ inches in diameter, an intermediate cylinder 37 inches in diameter, and two low-pressure cylinders each 55 inches in diameter, the stroke being 59 inches in length. All the cylinders are steam jacketed. The fly-wheel is 24½ feet in diameter, and has 45 grooves for 1¾-inch ropes, and weighs nearly 90 tons. The crank-shaft is of steel, the fly-wheel boss being 25½ inches in diameter and the journals 17¾ inches.

As is usual in German and Swiss engines, Corliss valves are replaced by double-beat drop valves, which give excellent results. The low-pressure cylinders are connected with the condensers, which are exhausted by double-acting air pumps worked from the crank pins. A 92 per cent. vacuum is frequently obtained. The crank-shaft bearings are continuously lubricated by oil supplied by centrifugal pumps, as are also the piston rods by oil-press pumps driven from the gear shaft. Well-constructed engines, of either of the types we have described, can be worked with a coal consumption of from 1¼ to 1½ lbs. per horse power per hour.

Another rather interesting type of engine, of which some examples are to be found in flax mills, is the high-speed Willans engine, or its Continental counterpart the Belleville engine. This is a triple or quadruple expansion engine, running at the enormous speed of over 300 revolutions per minute. Its general form is seen in fig. 154. The cylinders are superposed, one hollow piston rod serving for all and conveying the steam from one to the other. The speed is very steady, about 900 impulses being given per minute. On account of its high speed a very small fly-wheel is required, and all the parts are comparatively small and light, and being made to gauge, may be kept in stock. The whole engine occupies remarkably little space for the power developed. The principal bearings run in oil baths, the others being supplied with oil by circulating pumps.

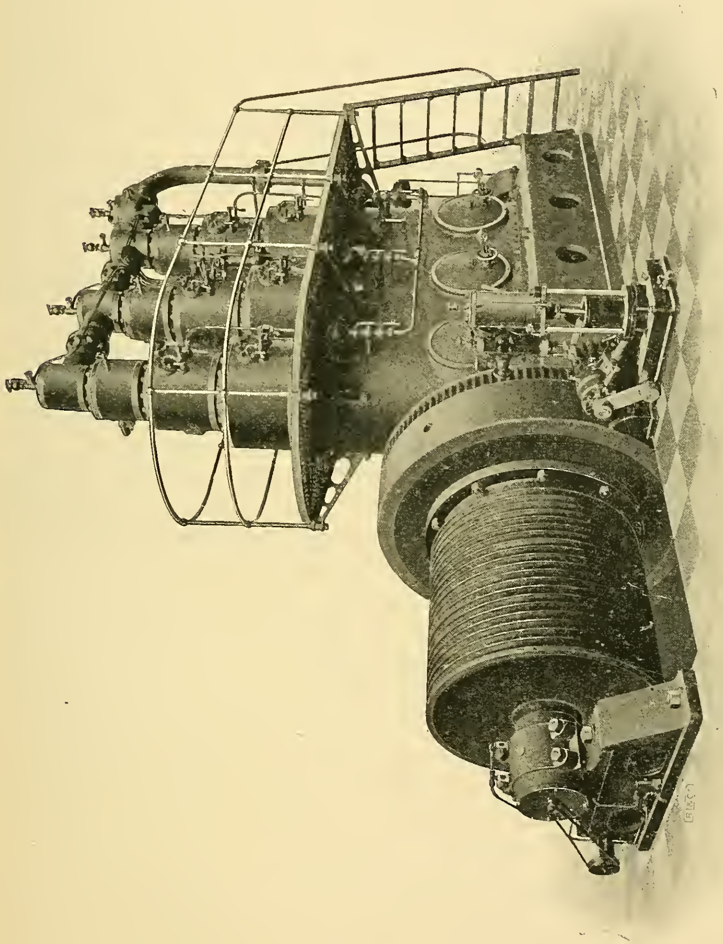

Fig. 154.—The Willans steam engine. As made by Messrs Willans & Robinson, Rugby.

The accessories usually found in the engine-house comprise steam gauges, to indicate the initial steam pressure as well as that in the receiver; a vacuum gauge, to show the workings of the condenser; a counter, to register the number of revolutions made in a given time; perhaps a speed indicator of the Butler type; and what may sometimes prevent serious accidents, a Tate's electrical stop motion. Instead of or in addition to the latter, a system of electric bells should be arranged with each room, by means of which the engineer may be warned to stop the engine immediately in case of accident. In no industry is a steady drive more essential than in that of spinning, especially of fine numbers. A very useful adjunct to the engine is an instrument known as Moscrop's Continuous Recorder, by means of which every momentary variation in the speed of the engine or shafting may be noted, as well as the times of starting and stopping the engine and the rise and fall of the steam pressure. The record is automatically kept upon a travelling paper band wound up at a regular speed by clockwork.

If an engine is required, it should be ordered of sufficient size to develop the power required when cutting off steam at one-fifth stroke. With modern engines the term "nominal horse power" has no meaning whatever. When applied to the old simple condensing beam engine it was of value in comparing the force of engines when calculated by dividing the piston area in square inches by 22, for a simple engine with a cylinder 30 inches in diameter might be said to be of $\frac{30 \times 30 \times \cdot 7854}{22}$ = about 70 N.H.P.

The brake or net horse power is now the only really satisfactory basis to go upon in denoting the power of an engine.

In the case of a small engine it may be determined by means of a dynamometer applied to the fly-wheel, or to a special pulley keyed upon the crank or first-motion shaft. In the case of large engines it is sufficiently accurate to deduct the power required to drive the engine alone, as found from the friction diagram, from the total indicated horse power.

*Indicators.*—Every mill should have a steam-engine indicator, which should be regularly used to detect defects in the working of the valve gear, etc., to show the operation of the steam engine generally, and to ensure economy in the use of steam and oil. The form of the indicator diagram shows the skilled engineer if the steam is being economically employed, if the valve gear and cut-off motions are working well and properly set to shut off and open at the most advantageous moment, if the piston rings and cylinder are worn and passing steam, etc., etc.

The steam-engine indicator is a most ingenious instrument, invented by Watt, and frequently improved and perfected to overcome difficulties imposed by increased piston speeds and augmented steam pressures. It is a steam cylinder in miniature, containing a piston rod and piston, the head of which has usually an area of 1 square inch. The steam acts only upon the under side of the piston head, its force being measured by the compression of a spiral steel spring, of known strength, which is interposed between the piston head and the cylinder cover. By employing at the same moment twice as many indicators as the engine has cylinders, or by connecting the same instrument in turn with each end of the several cylinders of the engine to be tested, the effective force of the steam during each respective outward stroke may be accurately determined, as may also the value of the vacuum or absence or degree of back pressure during the return journey of the piston. The end of the small piston rod protruding from the cylinder of the indicator is connected with an ingenious link or parallel motion and pencil arm, which latter, being brought in contact with a sheet of paper surrounding a reciprocating drum, describes a boot-shaped figure, the area of which is a sure measure of the force developed by the steam admitted at one end of the cylinder during one revolution and of the additional effect given to the force of the steam, when admitted to the other side of the piston, by the vacuum or reduction in back pressure. In order that the diagrams taken may be of a convenient size, it is usual to employ a stronger spring for high pressures or for the high-pressure cylinder than for the lower pressures of the intermediate or low-pressure cylinder.

For instance, to indicate a compound engine running at 60 revolutions per minute with 100 lbs. per square inch boiler pressure, a spring which will be compressed $\frac{1}{200}$ of an inch for each pound pressure per square inch may be employed for the high-pressure cylinder, and one which is compressed $\frac{1}{100}$ of an inch for each pound per square inch pressure for the low-pressure cylinder. Since, in the Tabor indicator, for instance, the pencil mechanism multiplies the piston motion five times, these compressions are equivalent to $\frac{1}{40}$ inch and $\frac{1}{20}$ inch respectively at the end of the pencil arm. So much for the height of the indicator diagram. Its length depends upon the diameter of the paper drum, usually about 2 inches, and the amount of angular motion given to that drum by the reciprocating motion of the piston of the engine. The proportions of the latter must naturally be reduced to about 5 inches to suit the dimensions of the indicator card. In the case of a low-pressure beam engine, this is easily done by connecting the cord, which turns the paper drum, to a suitable point upon the radius bar. Upon a modern horizontal engine, such as is shown in fig. 155, some sort of reducing gear or pantagraph will be required. That supplied by the makers of the Tabor indicator, comprising cord drum, worm, and worm wheel upon the paper drum, may be applied to indicators of all makes, or a combination of levers and links may be devised to accomplish a like

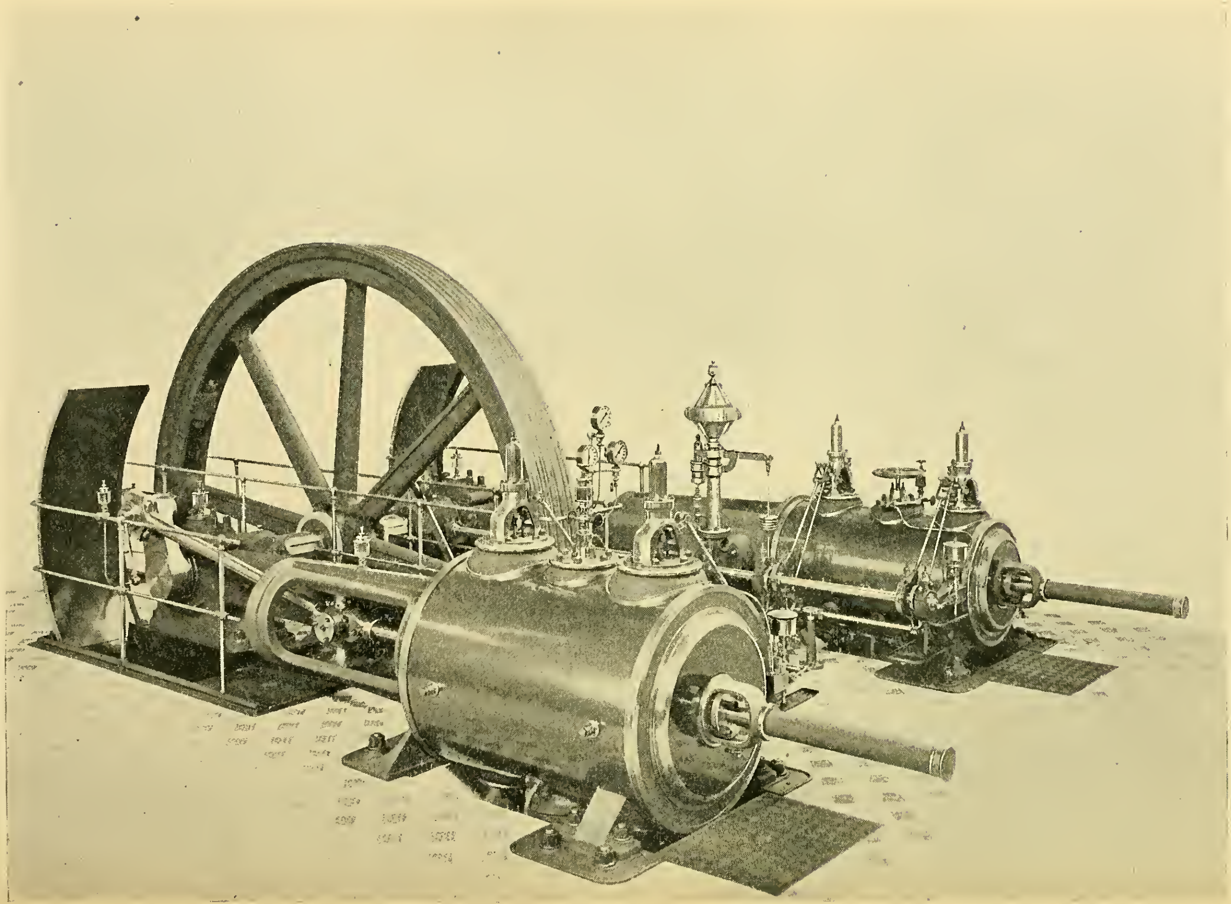

FIG. 155.—Sulzer's horizontal compound mill engine.

result. While the pull of the cord pulls the paper drum round in one direction, a coiled spring is required to bring it back again and take up the slack of the cord upon the return journey of the piston.

The way to use the indicator is as follows :—

Attach the instrument, by means of a screwed coupling provided, with the indicator cock to be found at either end of the cylinders of all modern engines. Unscrew the cylinder cover of the indicator and lift out with it the piston, to the head of which apply a small quantity of cylinder oil and replace, making sure that the spring inserted between the piston head and the cylinder cover is the proper one for the cylinder and engine to be indicated. Oil the pivots and joints of the pencil mechanism from time to time with a light oil—watch oil preferred—and make sure that they work perfectly smoothly and freely. Turn on the steam and heat the apparatus thoroughly. Fix a piece of paper of suitable size around the paper drum, where it is held by the clips provided. All being now ready, take the hook attached to the cord surrounding the cord and paper drum in one hand, and pull out the cord to its full extent in the direction of the reducing gear or the point to which it is to be attached with the cross head of the engine. The correct point of attachment will thus be found to give the paper drum the necessary movement without touching the stops at either end, or a circumferential distance of about $5\frac{1}{2}$ inches. The length of the cord is easily adjusted when required by means of a cord adjuster, such, for instance, as that supplied with the Tabor indicator. A suitable traverse having been obtained, the atmospheric line is first traced by bringing the pencil on the swinging pencil arm in contact with the paper on the reciprocating paper drum, the cocks being, of course, shut. The cocks are then opened, and after any small accumulation of water has been allowed to escape, the pencil is again brought into contact with the paper, and a boot-shaped figure is traced, when the steam may be shut off again, the cord disconnected and the instrument removed to the indicator cock at the other end of the cylinder, where the operation is repeated, the same paper serving for both diagrams, which will be traced at opposite ends of the card. The changing of the instrument from one end of the cylinder to the other may be avoided by connecting together the cocks, at either end of the cylinder, by a pipe, in the centre of which a three-way cock is fitted, to which the indicator may be attached. Moving the handle of this cock to either side puts one or other end of the cylinder in communication with the indicator, and diagrams from both ends may be quickly taken on the same paper without changing the position of the indicator.

In order that the indicated horse-power, as calculated from the area of the diagrams, may be absolutely accurate, it is essential that both ends of each separate cylinder should be indicated at one and the same moment. To do this one must, of course, be provided with two, four, six, or eight instruments for simple, compound, triple, and quadruple expansion engines. An ingenious electrical attachment may be employed to enable *one* engineer to take all these diagrams at the same identical moment, a result which would be difficult to achieve by a number of men working in concert. It consists of an electro-magnet fixed to the barrel of each indicator and connected by wires to a switch on the battery box which the operator keeps beside him. Springs are used to keep the pencils out of contact with the papers until the current is switched on, when the electro-magnets attract armatures attached to the swivel plates and bring the pencils against their respective paper drums, the steam having been first turned on and the driving cords attached.

When only one instrument is available, the spring must be changed to indicate the high and low pressure cylinders respectively. The spring is, as we said, inserted between the piston head and the cylinder cover. In the Tabor indicator a small thumb-screw with ball and socket joint unites the piston rod to its head, which is in turn screwed to the lower portion of the spring, the upper end of the latter being screwed to the cylinder cover.

Looking first at the form or shape of the diagrams, which have been traced upon the cards, in order to see that the valves have been properly set, that the piston rings are steam-tight, and that the steam is economically employed, we will find that the figures taken from the high-pressure cylinder of a compound engine lie entirely above the atmospheric line, while those from the low-pressure cylinder lie chiefly below it. The height to which the former extends above the atmospheric line indicates the intensity of the initial steam pressure above the pressure of the atmosphere. On measuring this height to the scale of the spring used, it will be found to be less than the boiler pressure, in consequence of condensation in the connecting steam pipes, etc., and it should be the aim of the engineer to reduce this inequality and thereby save coal. The height to which the low-pressure diagram reaches above the atmospheric line indicates the pressure at which the steam was admitted to the low-pressure cylinder, which should be as nearly as possible the same as that at which it left the high-pressure cylinder. The distance to which the low-pressure diagram descends below the atmospheric line indicates the degree of vacuum produced by the condenser, which should, of course, be as nearly perfect as possible.

In either high or low-pressure diagrams the line which encloses the figure at the bottom will be found to be nearly horizontal, and is that traced during the return stroke of the piston when it is pushing the rarified steam before it into the receiver or condenser respectively. At either the right or left hand side of the figure, according to the end of the cylinder considered, it is curved upwards, indicating a rise in pressure, due to the closing of the exhaust port with the object of forming a cushion of steam to bring the piston to rest at the end of the stroke without shock. The point at which this curve begins, and the height at which it reaches a vertical line bounding the extremity of the figure, indicates if the port has been closed too soon or too late. The line of steam admission and the rise in pressure thus produced mingles in with the line of compression, and it is rather difficult to separate them. If, however, this line, after reaching the vertical line already referred to, again recedes from it before attaining its full height, it may be taken as a sign that the admission of steam takes place too late. If, on the other hand, this line reaches a considerable height before touching the vertical line bounding the end of the stroke, it may be taken that the steam is admitted too early. After the figure has attained its maximum height, the top line, traced during the outward stroke of the piston, should be nearly horizontal, showing that the pressure has been kept up until the cut-off takes place. If this line falls away at once, before the point of cut-off, it shows that the steam is *wire drawn*, or that the steam pipe from the boilers or the valves are of insufficient section to supply the quantity of steam required by the speed and power of the engine. The abruptness of the angle at which the line of steam expansion leaves the line of steam pressure indicates the sharpness of the cut-off, depending in some cases on the quality of the oil with which the Corliss valves are lubricated. The cut-off should, of course, be as sharp as possible. The fraction of the stroke at which it takes place is shown upon the diagram by measuring the distance of the angle of cut-off from the end of the figure and comparing that distance with the total length of the latter. After the point of cut-off comes the expansion curve, which should approach the hyperbolic as nearly as possible. The abrupt fall in the expansion line, near the extremity of the diagram, indicates the point in the stroke at which the exhaust port was opened.

In order that full advantage may be taken of the steam expansion, exhaust should take place as late as possible, but always in time to let the line fall to its lowest position before the end of the stroke or the extremity of the diagram. The line running almost horizontally at the bottom of the figure is the back pressure or vacuum line, and completes the diagram of the cycle of operations.

Defects sometimes met with in the indicator diagram are: Serrations in the steam line caused by the oscillations in the reciprocating parts of the instrument; fall of the expansion curve below the hyperbole, due to a badly-fitted piston or oval cylinder; a loop formed by the admission line and the steam line generally, indicating that the exhaust closes too early in the stroke and that the steam remaining in the cylinder is compressed until it reaches a pressure exceeding that of the boiler, falling again when the steam port is opened.

To calculate the I.H.P., or indicated horse-power, from the diagrams, we must first measure the average effective pressure as shown by the height of the figure. This may be done with the aid of a Coffin averaging instrument, or merely by measuring the height of the figure at, say, ten equidistant points and taking the true average of these measurements.

In using the averaging instrument above referred to, the tracing point is moved carefully along the line of the figure until the circuit is complete, when the reading of the graduated wheel is taken, representing the area of the diagram. The mean height corresponding with the average effective pressure is, of course, the area of the figure divided by its length.

The other particulars required for power calculation are: The area of the piston and piston rod and the speed of the piston. The area of the piston and rod, which must be taken, under the British system, in square inches, is ascertained by squaring the diameter of the piston or rod respectively in inches and multiplying by the decimal fraction ·7854. The speed of the piston in feet per minute is found by taking the length of the stroke in feet, or twice the length of the crank measured from the centre of the crank axle to the centre of the crank pin, and multiplying by the number of strokes per minute or twice the number of revolutions. The I.H.P. is then the product of the three factors—*i.e.* the mean effective pressure as obtained from the indicator diagrams, the area of the piston in square inches, and the piston speed in feet per minute, divided by the 33,000 foot pounds taken as the equivalent of one horse-power. In compound and triple-expansion engines this calculation must be made for each cylinder, the mean effective pressure being the average height of the diagrams from both ends taken together, and the results added together to obtain the total I.H.P. of the engine. To be absolutely accurate, the area of the piston rod, if it does not pass through both ends of the cylinder, must be deducted from the area of the piston when calculating the diagram for that end, or, what is simpler, one-half the area of the piston rod deducted from the piston area, and the effective area thus obtained used in calculating both diagrams together as described. When the piston rod passes through both ends of the cylinder its full diameter must of course be deducted from the piston areas. In continental practice the calculations for I.H.P. are similarly conducted, the areas being taken in square centimetres, the pressure in kilogrammes per square centimetre, and the piston speed in metres per second. The basis of horse-power is the moving of 75 kilogrammes through a distance of 1 metre per second. The following conversion factors may be found useful in this connection:—

Pounds per square inch × 0·0703 = kilos. per square centimetre.
British horse power × 1·0139 = force de cheval.
Kilos. per square centimetre × 14·223 = pounds per square inch.
Force de cheval × 0·9863 = horse-power.

With the aid of the indicator, etc., a useful trial may be made to find the efficiency of the coal, boiler, and engine in the following way:—Make sure that all steam valves and joints are tight, and that no steam escapes or is used other than by the engine. Prepare a method of measuring the water used by the boiler during the trial, either a water metre or a reservoir of regular form and sufficient capacity, the contents of which before and after the trial may be accurately calculated. Stop the engine for a few minutes in order that the water level in the boiler may be accurately marked, in order that it may be re-established at the end of the trial. Note also the steam pressure before and after the trial. Start the engine and take the diagrams frequently, say every quarter of an hour during the duration of the trial; note the number of revolutions made during that time by means of a counter, in order that the average speed per minute may be accurately determined. To terminate the trial, the water level in the boiler should be brought up to the same height as at the start, as should also the steam pressure. The coal used may then be noted, as may also the gallons of water used to maintain the water level in the boiler, and the average I.H.P. calculated from the diagrams taken and the average revolutions noted. A gallon of water weighing 10 lbs., the weight of steam used may be easily calculated, as may the pounds of water evaporated per pound of coal and the coal consumed per indicated horse-power and per hour.

To be absolutely exact, the water condensed in the connecting steam pipes should be deducted from the quantity of water introduced into the boiler, as should also any water which, owing to priming of the boiler, goes to the engine with the steam. The amount of priming, if any, may be detected by putting a measured quantity of salt into the boiler and evaporating the water of condensation from the steam piping. The quantity of salt which is found in the latter, in proportion to that put into the boiler and its capacity, will give the quantity of water to be attributed to priming.

# CHAPTER XXI.

## POWER TRANSMISSION—BELTS, ROPES, AND GEARING—ELECTRICAL POWER TRANSMISSION.

*Power Transmission.*—The development of power transmission by electricity is of such comparatively recent date that it is only employed in some of the newest mills and in some extensions to existing mills. In the latter case it has generally been adopted by reason of some difficulty in extending existing lines of shafting, owing to distance or mechanical inconvenience. Although it may not be the most economical method of transmitting power over short distances, still it is the only practicable method when a long distance has to be covered, and in every case it is an exceedingly handy and convenient method of power transmission, in that the speed of the driven shaft or machine may be changed at will and at work. The method of its application is as follows:—The power is generated by water, steam turbine or steam engine, as described in our last chapter, and utilised to drive the electric generator or dynamo, which may either be directly coupled or driven by a belt or ropes. The electric current supplied by this latter machine is then available to be conveyed any distance, through copper wires of suitable section, and utilised to impart motion to an electric motor or motors coupled directly to the shafting or machine to be driven, or driving them by means of a belt or ropes. Fig. 156 shows such an arrangement, *i.e.* a Westinghouse motor driving, by means of ropes, a line shaft which is in turn driving some twisting frames. The speed of the motor, and consequently that of the machine which it drives, may be altered by diminishing the voltage pressure or intensity of the current supplied by means of a resistance frame or rheostat.

One of the largest applications of electric driving to textile mills is that recently awarded to the British Westinghouse Co., Ltd., by Messrs Birkmyre Brothers to drive their jute mill on the river Hugli, near Calcutta. The motive power is furnished by steam turbines. The exciter generators, of 20 K.W., are mounted direct on extensions of the turbine shaft. The turbo generators are of 1300 K.W. capacity, and furnish a three-phase current at 440 volts and 25 periods. The greater part of the driving is done by three 700-horse-power motors running at 290 revolutions per minute, and directly coupled to the shafting.

The direct coupling of the motors to the shafting is the method usually employed, being the least costly. The provision of a small motor for each machine, though convenient, is usually considered to be too expensive.

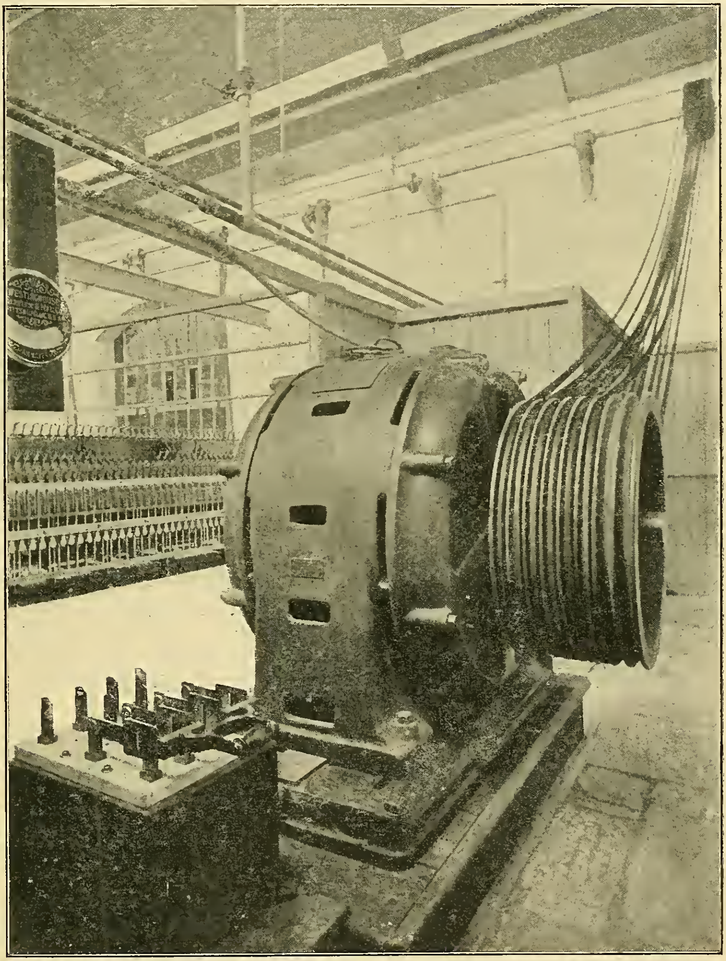

FIG. 156.—Westinghouse polyphase motor operating twisting frames.

*Gearing.*—The oldest method of power transmission is undoubtedly by means of toothed gearing. It is the only one which can be absolutely relied upon for accuracy, as both belts and ropes are capable of slipping. A great deal of science is required to construct the teeth properly, in order that the friction between them shall be the least possible. The pitch of the teeth of small wheels is recognised as so many teeth per inch diameter. The diameter of the wheel is measured on the pitch circle, and is equal to the extreme diameter minus the depth of one tooth. The pitch of large wheels for mill gearing, however, is measured along the pitch circle, and is equal to the circumference of that circle divided by the number of teeth in the wheel. For wheels of this class, the thickness of the tooth as measured along the pitch line is equal to the pitch × 0·48. The space between the teeth is therefore 0·52 × pitch. The length of the tooth from the pitch line to the point should equal the pitch × 0·30, and the length from the pitch line to the bottom of the tooth = 0·36 pitch. When such wheels are used to transmit power, one wheel of each pair may be fitted with wooden teeth morticed into the metal rim of the wheel and held by a pin passing through the tail end inside the rim. Such a wheel is called a mortice wheel. Its object is to give smoothness to the drive, and to reduce noise and vibration. With the same object, wheels built up in segments separated by blocks of indiarubber were also used, and later still, helical teeth, extending askew across the face of the wheel or arranged herring-bone fashion. When wheel gearing is used to drive a mill of several storeys, the fly-wheel of the engine is toothed and drives a spur pinion on the second motion shaft. Upon this shaft a bevel wheel gives motion to a vertical shaft, the base of which rests in a huge footstep, which on account of the weight upon it, requires a great deal of attention. The line shafts upon each storey of the mill are driven by bevel wheels, one of them a mortice wheel, from the vertical shaft.

*Rope Driving.*—In mills of modern construction, and in old mills where old engines have been thrown out and replaced by new ones, wheel gearing for the main drives has been entirely superseded by rope driving, which is much more convenient. The fly-wheel of the engine is grooved for the ropes, the number of which depends upon the power to be transmitted and the manner in which it is to be distributed. A rope $1\frac{3}{4}$ inches in diameter is a very convenient size to use. At a speed of 4500 feet per minute, which is a good average velocity when transmitting power from large rope fly-wheels, a good three-strand cotton driving rope will transmit 45 horse-power, if the diameter of the smallest pulley be not less than 4 feet 5 inches, or thirty times the diameter of the rope. Other diameters of ropes will transmit forces proportional to the squares of their diameters. The power which may be transmitted is also directly proportional to the velocity of the rope in feet per minute, which velocity should never exceed 4800 feet, since at high speeds the tension available for the transmission of power is considerably reduced by the centrifugal action of the rope.

The sides of the groove in which the rope works should be inclined to each other at an angle of about 45°. A very good form of groove which is recommended by Messrs Wm. Kenyon & Sons, Dunkinfield, Manchester, whose three-strand cotton ropes enjoy a world-wide reputation, is shown in fig. 157.

Their method of setting out the groove as here shown possesses two good qualities, viz., accuracy and simplicity. Referring to the diagram, it will be seen that the first thing to do is to draw a circle the diameter of which corresponds with that of the rope, and then to draw in the central lines both vertically and horizontally. The points A and B are then joined, and the length of this line becomes the standard of all succeeding measurements. By measuring off this length from the centre of the circle downwards along the vertical centre line, a centre is found for rounding off the bottom of the groove, and twice that distance along the same line fixes the apex in which the lines passing through B B converge.

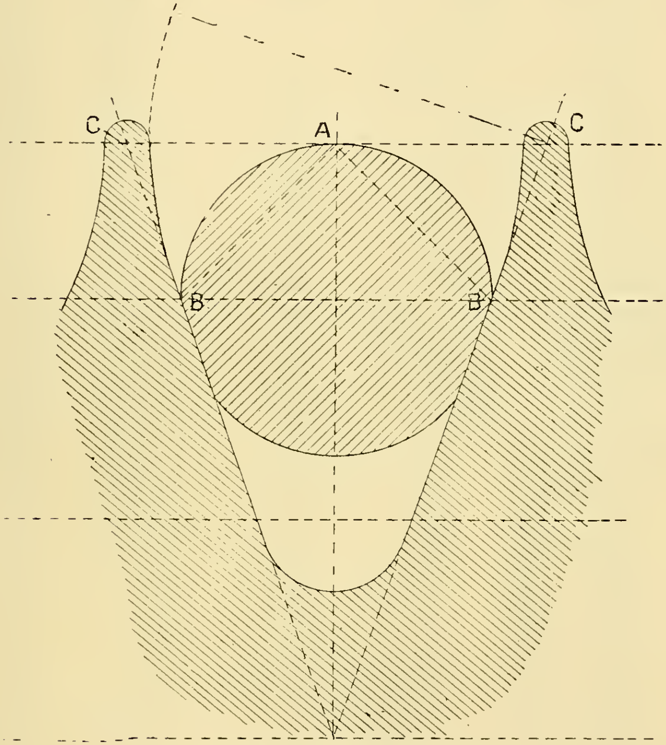

Fig. 157.—Method of setting out groove.

The centres for rounding off the mid-feathers, or upper portions of the groove, are situated in a horizontal line drawn parallel to B B through the point A. These centres C are distant from A a space equal to A B.

The rope should be of sufficient diameter to rest on the sides of the groove, and not on the bottom. The resistance to slipping is very great without wedging, and the weight of the rope helps it to leave the groove without loss of power.

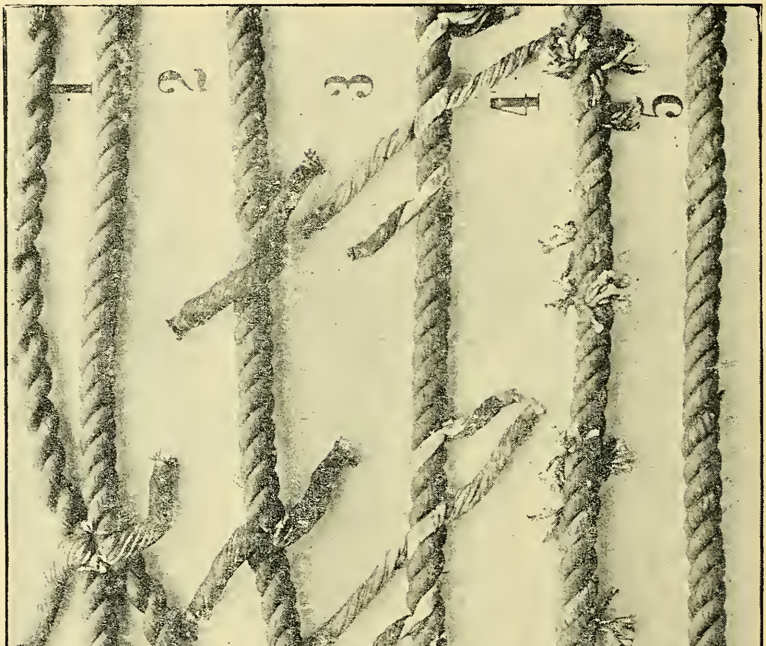

Fig. 158.—Method of splicing driving ropes.

In horizontal or inclined drives the power transmitted is somewhat increased. When the slack side of the rope is on the top, the rope will run more steadily, and be less liable to run or leap out of the groove than when the slack side is underneath. When starting a rope-drive all the ropes should, if possible, be put on at the same time, to the same length, and consequently at equal tensions. Each rope will then do like amounts of work, and all will stretch alike and in a minimum degree.

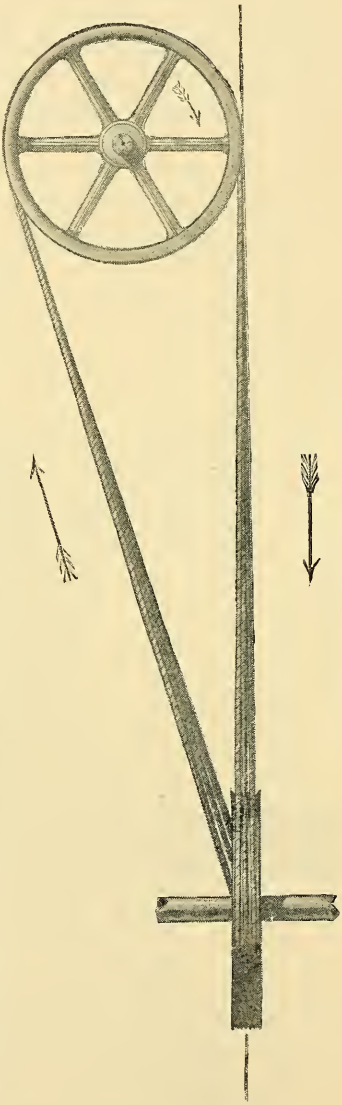

Fig. 159.—Half crossed vertical driving.

The ends of the rope are joined or made continuous by means of a splicing, which should be carefully done by an expert rope splicer. If the splice be clumsily made, that part of the rope will be thicker, and the rope will run unsteadily and have a tendency to leap from its groove.

The method of splicing is shown in fig. 158.

The length of the splicing should not be less than seventy-two times the diameter of the rope, or say 10 feet 6 inches for a $1\frac{3}{4}$-inch rope. The first operation is to measure off a distance equal to half the length of the splices from each end of the rope after its measurement has been taken with a cord, or by calculation, and the length of the splice added.

Then take out and cut away one strand from each side and whip the ends together at that point as shown in section 1 of the figure. Another strand from one side is then untwisted, and followed up and replaced by a strand from the other side as shown in section 2. The same thing is done with the other side, and the long ends cut off and thinned down by stripping off the outer shell as shown in section 3. These loose ends are then worked in round the strands and through the rope with the aid of a marlinspike, as in section 4, and then the remainders cut off, leaving the splice complete, level and smooth as shown in section 5.

Ropes usually serve to drive a shaft lying parallel to another, both driving and driven pulleys being in the same vertical plane. As seen from figs. 159 and 160, these conditions are not essential, and shafts at right angles to each other may be driven by either a half crossed vertical rope or with the aid of guide pulleys.

Tolerably long centres are a decided advantage to ropes working in the position shown in fig. 159, particularly if the pulleys are of large diameter. Long keyways should be cut in both shafts so that the pulleys may be brought into their best driving position, the theory being that the central groove of each pulley on the running-on side should be in the same vertical plane as the face of the other pulley.

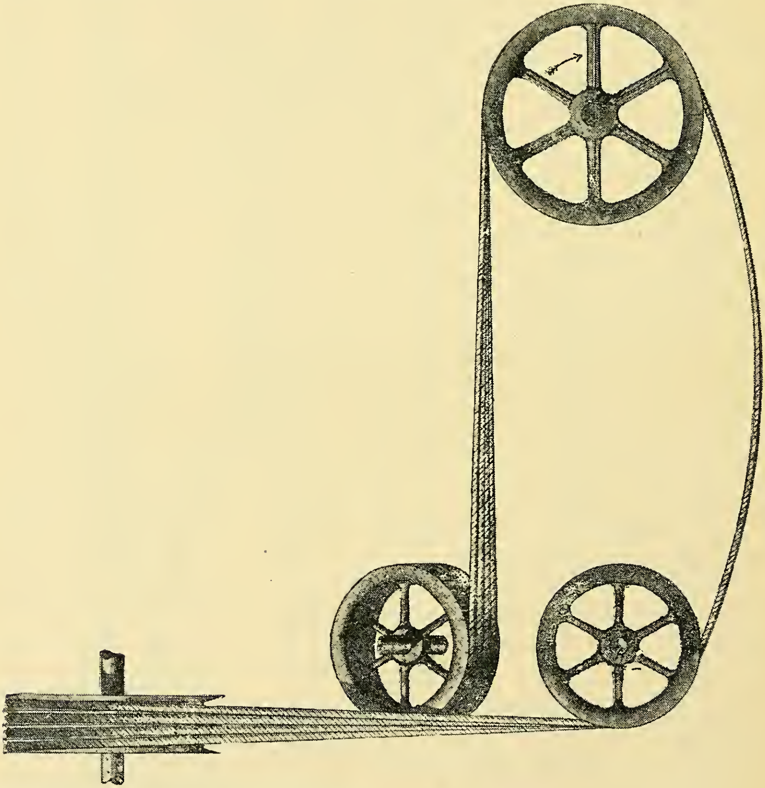

Fig. 160.—Driving with shafts at right angles.

Shafts lying at any angle to each other may be driven with the intervention of guide pulleys, as shown in fig. 160, the same conditions as above being observed in placing the guide pulleys in position.

Fig. 161 illustrates an arrangement which has been patented by Messrs Wm. Kenyon & Sons for driving spinning frames, roving frames, twisting frames, lathes and other light mill machinery by means of fast and loose

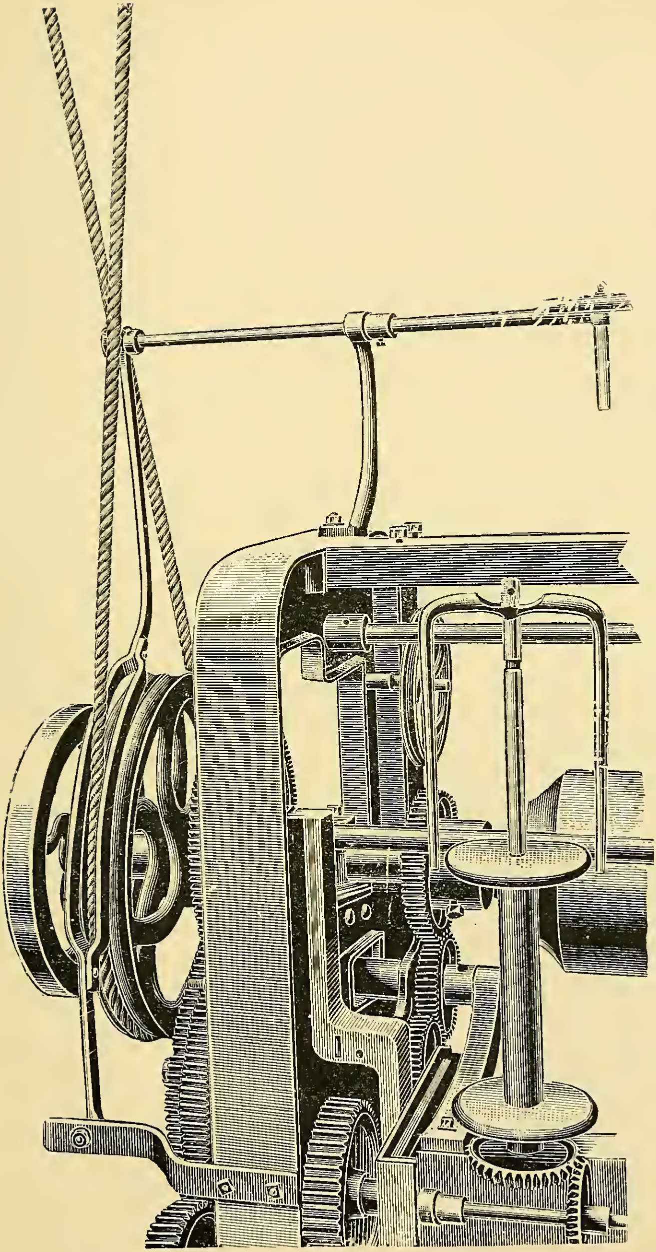

FIG. 161.—Application of rope driving to machinery by patent fast and loose pulleys.

pulleys. The rope is passed from fast to loose pulley by an ordinary fork or belt shifter, which, however, takes the curve of the pulley itself. A $\frac{1}{2}$-inch cotton rope will in this way do the work of a 3-inch belt.

The American system of continuous driving is only mentioned to be condemned. This method of conveying a considerable force by means of one rope, wound round and round the pulleys and guided from side to side by large jockey pulleys fixed in slides and used as a means of maintaining a regular tension, is most severe upon the rope on account of the useless friction and angular wrench to which it is subjected. Besides, if the single splice breaks, the machinery must be stopped, whereas if a series of ropes be used the loss of one of them for a few hours can usually be borne without danger or inconvenience.

Although cotton is now generally allowed to be the best material for driving ropes, Manila and leather ropes are still used, especially on the Continent.

The machine-made Manila rope manufactured as described in Chapter XVII. is superior to the hand-made, in that it may be had in greater lengths, and is usually composed of finer yarns.

A French firm make a speciality of an 8-strand square and plaited rope for which they claim great flexibility and absence of stretch. Such a rope cannot turn in the groove as round cables frequently do. It used to be considered that the rolling of a rope in its groove tended to equalise the wear and gave the rope a longer life, for which reason the pulleys were often placed slightly out of line in order to induce rolling. The advantage of a turning rope is now denied, and the author's experience, at least as far as cotton ropes goes, tends to confirm this idea.

Leather ropes of buffalo hide are extremely durable on easy drives, but are hard to splice and require frequent tarring. The life of a Manila rope is considerably increased by regular oiling with castor oil, for instance, since, if unlubricated, the friction between the strands, in bending round the pulleys, tends to wear the interior of the rope and reduce its strength.

*Belt Driving.*—While a rope is prevented from slipping by a wedging action in its groove, a belt drives by reason of its grip or friction on the flat surface of a pulley. The greater the power to be transmitted, the greater must be the area of the surfaces in contact, hence the frequent slipping on pulleys of small diameter, and the reason why their use should be avoided when possible. Inequalities in the surface of the belt permit of the interposition of a body of air between its surface and that of the pulley, and reduce its driving power. This circumstance led to the introduction of the perforated rim pulley, the makers of which, however, lose sight of the fact that the perforations, through which the imprisoned air escapes, reduce considerably the area of the surfaces in contact. When there is perfect contact between belt and pulley and no air cushion, the pressure of the atmosphere is unbalanced and exerts its full effect. The arc of contact between belt and pulley is increased by having the sag or slack side of the belt on the top, whenever possible, in horizontal and inclined drives. The greater the length of the belt, and also the more alike in diameter the driving and driven pulleys, the better. In no case should the proportion between the diameters of two pulleys working together exceed 6 to 1. The face of the pulley is usually made convex in order that the belt may remain in the middle in consequence of the tendency which a tight belt always has to run to the high side. The convexity should not be less than $\frac{1}{8}$ inch nor more than $\frac{1}{4}$ inch per foot in width. The pulley should be at least $\frac{1}{2}$ inch wider than the belt. About 3500 feet per minute is a good average speed for main driving belts, and about half that for frame belts. When a belt is doing no work, the tension upon both its sides is alike. When the belt is transmitting force the tension of the driving side exceeds that of the slack side by an amount proportional to the force transmitted. The force transmitted thus depends upon the difference in tension between the two sides of the belt and upon its surface speed. If $T =$ the working tension of the tight side of the belt in pounds, $t$ the tension of the slack side in pounds, and $V$ the velocity of the belt in feet per minute, then the force transmitted is equal to $\frac{V\ (T - t)}{33{,}000 \times 2}$ horse-power.

The ultimate strength of single leather belting is about 700 lbs. per inch in width, the usual working tension about 110 lbs. per inch in width, and the tension when at rest about 20 lbs. per inch in width. Hence at a velocity of 3500 feet per minute, a single leather belt 1 inch in width will transmit $\frac{3500\ (110 - 20)}{33{,}000 \times 2} = 4{\cdot}77$ horse-power. Upon this basis the width W of single-leather belting required to transmit any given number of horse-power at any given speed may be determined from the equation $W = \frac{3500 \times \text{H.P.}}{4{\cdot}77\ \text{V.}}$ where $V =$ the velocity in feet per minute and H.P. = horse-power.

The horse-power required to drive any machine may be determined in the following way :—Pass a strong cord through the hole which is usually to be found in the face of the fast pulley and make a knot or attach something in the inside which will prevent its drawing through. Give the cord a partial or a whole turn around the pulley and attach a Salter's spring balance, by means of which the pull necessary to start the frame may be seen. The tension thus indicated, multiplied by the working velocity of the belt in feet per minute and divided by 33,000, will give the horse-power required to drive the frame.

For mill work, leather is best adapted for ordinary drives in dry rooms at ordinary temperatures, such as preparing rooms, dry spinning rooms, ropeworks, etc. For hot or damp rooms, such as wet spinning rooms, etc., the author believes in the use of a reliable brand of camel's-hair belting, which is exceedingly strong and pliable, and is unaffected by changes of temperature, water, steam, etc. It is much lighter than many other textile belts, hence the pull upon the bearings, due to the weight of the belt, is reduced to a minimum, as is also the effects of centrifugal tension. Leather belting should be regularly oiled upon its back with castor oil in order to keep it in good working condition, while camel's-hair belting should be treated with a good belt syrup for a like reason, and also to increase its gripping power. Leather belting should be joined with belt laces, and textile belts by bifurcated rivets or similar fasteners, care being taken that all the joinings run in the same direction, which should be such that, if there be any slippage upon the smaller pulley, the joinings may be subjected to the least injury.

*Rules in connection with Rope and Belt Driving.*—The following rules in connection with belt and rope drives may be found useful.

1. To find the velocity of a rope or belt in feet per minute, the pulley diameter and the number of revolutions per minute being given :—Multiply the working diameter of the pulley in feet by 3·1416 and by the number of revolutions per minute.

2. To find the number of revolutions of a *driven* pulley, the number of revolutions of the driving pulley and the diameters of both pulleys being given :—Multiply the number of revolutions of the *driver* by its diameter, and divide by the diameter of the *driven*.

3. To find the diameter of a *driving* pulley, the diameter of the driven pulley and the revolution per minute of each being given:—Multiply the diameter of the driven pulley by its speed, and divide by the speed of the driver.

4. To find the diameter of a *driven* pulley to make any given number of revolutions, the diameter and speed of the *driver* being given :—Multiply the diameter of the driving pulley by its speed, and divide by the required speed of the driven pulley.

5. To increase or diminish the length of rope or belt for a change of pulleys :—Multiply half the difference in diameters of the pulleys by 3·1416, and the result will be the length by which the belt or rope must be lengthened or shortened.

6. To find the length of belt or rope necessary for any open drive :—To twice the distance from centre to centre of shafts add the amount required for the joint or splicing, and also the product of half the sum of the pulley diameters and 3·1416.

Thus the length of $1\frac{1}{2}$-inch rope necessary for a drive where the distance from centre to centre of shafts is 60 feet, driving pulley 24 feet diameter, and driven pulley 4 feet in diameter, is $(2 \times 60) +$

$\left(\frac{1\frac{1}{2}\times 72}{12}\right) + \left\{ 3{\cdot}1416 \times \left(\frac{24+4}{2}\right) \right\} = 120 + 9 + 44 = 173$ feet, allowing 9 feet, or seventy-two times the diameter of the rope, for the length of the splicing.

The length of belting required for a crossed drive depends so much upon the relative diameters of the pulleys that it is better to determine the length of the belt by actual measurement with an inextensible cord.

*Pulleys and Bearings.*—Rope pulleys are always of cast iron. Belt pulleys are either of cast iron, built up of wrought iron with a cast iron centre, or of wood. Wrought iron pulleys are less liable to breakages, and much safer, especially when running at high speed. Wooden pulleys can only be used in dry rooms, and are liable to warp and become slack upon the shaft. Pulleys should always be of the "split" pattern, or made in two halves to facilitate mounting upon the shafting.

For heavy drives they should always be keyed on. For light drives it is usually sufficient to tighten them on, if they be bored out a sharp fit for the shafting.

The shafting is usually of wrought iron or steel, and is either solid or hollow, the latter being stronger, weight for weight, and cheaper, if the cost of transport is high. It is subjected to two strains—*i.e.* that produced by torsion, and the other due to the weight of the pulleys and pull of the belts and ropes. The amount of the first depends upon the length of the shaft. The second is overcome by the provision of bearings at frequent intervals, and when possible, by balancing the strain of the belt upon either side of the shaft. When the shafting is merely used to transmit power, the distance apart of the bearings may be obtained from the formula $L = 5\sqrt[3]{d^2}$, where $L =$ the length in feet between the supports and $d$ the diameter of the shaft in inches. If the shaft carries pulleys, etc., the formula $L = 4{\cdot}8\sqrt[3]{d^2}$ should be used. A 3-inch line shaft will transmit 45 horse-power when running at 150 revolutions per minute. The power transmitted by shafting varies directly as its velocity and as the cube of its diameter.