of a horizontal shell of boiler plate, from 7 feet to 12 feet in diameter, about two-thirds full of water, just below the surface of which are long oval pipes, whose lower sides are perforated with holes. The exhaust steam enters these pipes and bubbles upwards through the water, which absorbs the excess of both sensible and latent heat contained in the steam, the whole mass of water rising steadily in temperature, and the steam above it in both temperature and pressure, so long as the supply from the engines exceeds that taken by the turbines.

But the temperature at which water boils depends upon the pressure of the steam above it, a particular boiling point corresponding to every pressure. Consequently, when the supply of steam from the engines ceases, or is insufficient to maintain the supply to the turbines, so that the pressure above the water begins to fall, some of the water instantly boils off into

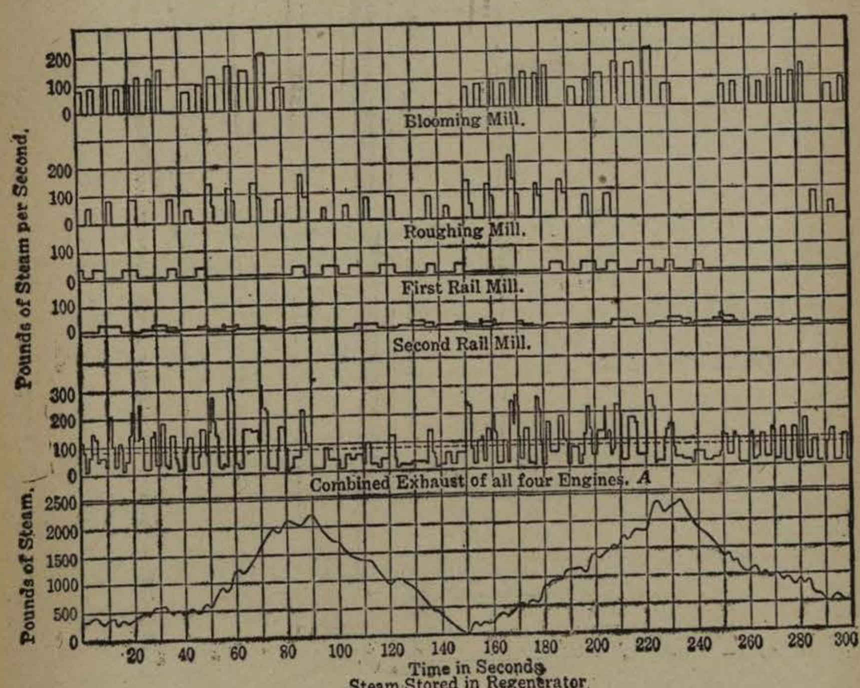


Fig. 430.—Storages of Heat from Exhaust Steam in a Rateau Accumulator.

steam, the supply of heat necessary to effect the change of state from water to steam being provided by the surplus heat in the water over and above that corresponding to the pressure.

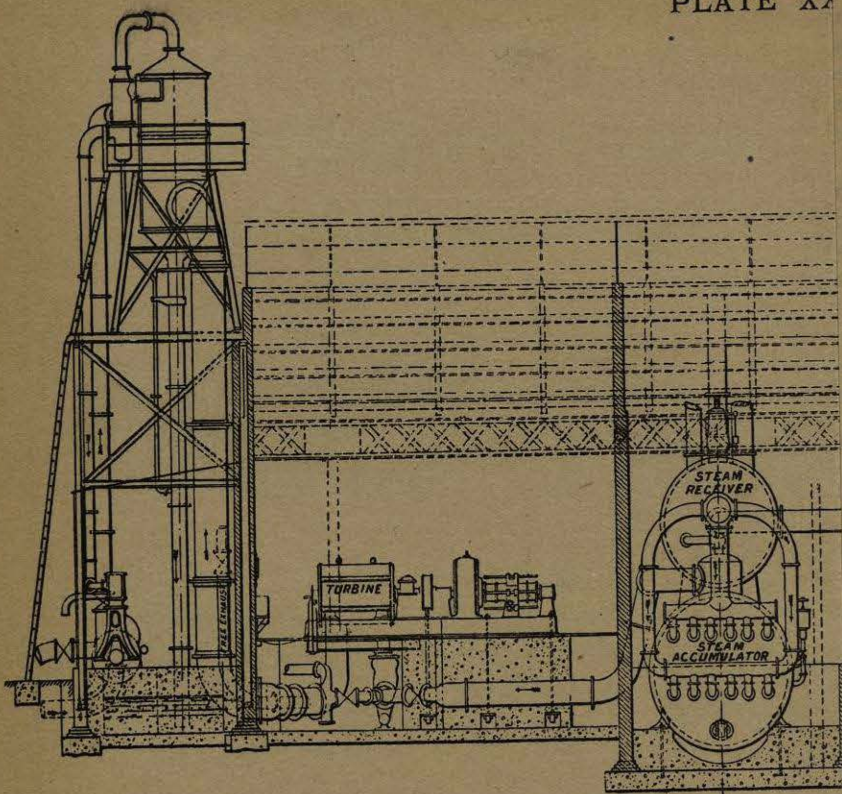
In this way the irregular and intermittent gusts of the exhaust from the engines are transformed into a steady flow for use in the turbine, the pressure gradually rising and falling very slightly with the supply. The variation in temperature is usually from 5° to 7° F., and in pressure from 2 to $2\frac{1}{2}$ lbs. per square inch only. Seeing that water at the temperatures employed occupies only $\frac{1}{1200}$ to $\frac{1}{1500}$ of the volume of the steam formed from it, storage of heat in the water is possible, while storing of the steam itself would be impracticable.

The length of time during which the turbine can be kept running after the supply of exhaust steam ceases depends upon the quantity of water

[To face p. 685.]

PLATE XX

Fig. 431.



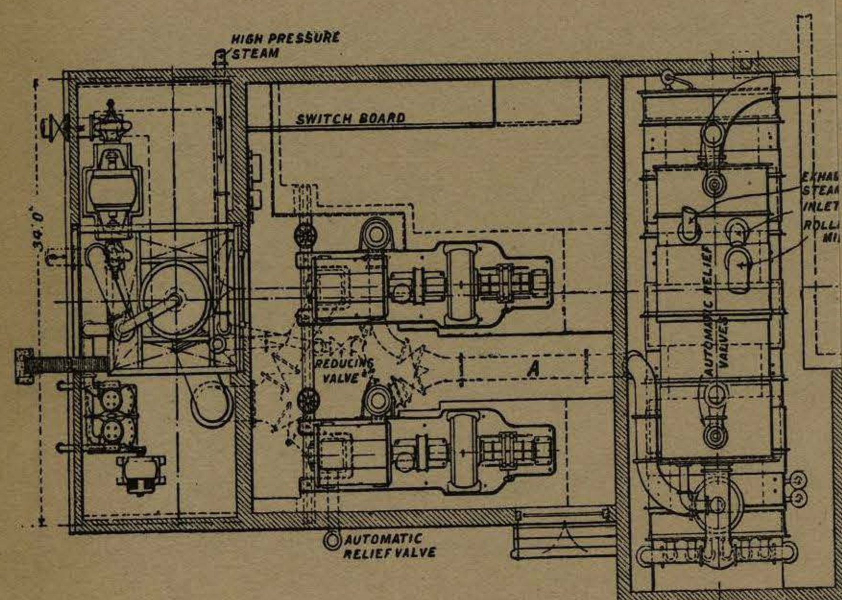


Fig. 432.

which the accumulator contains, and is determined by considerations of first cost. Where several engines exhaust to one accumulator they are not likely to be all stopped or reversed simultaneously, and the problem is simplified. Provided the total cessation of supply does not exceed 45 seconds, 50 tons of water will suffice to supply a turbine which consumes 37,000 lbs. of steam per hour. In practice sufficient water is usually provided to allow for stoppages of from ½ to 2½ minutes.

In fig. 430 the exhaust steam actually measured as flowing from each engine working in a rail mill is shown separately, and in the curve, A, below, the combined exhaust from all four engines together, which at some moments is practically nothing, and at other moments at the rate of over 300 lbs. weight per second. A mean line drawn through the crests and hollows of these waves gives 80 lbs. per second as the mean flow. In addition to these momentary variations, there is in the particular instance illustrated a gradual rise and fall having a period of about one minute, as shown by the irregular line at the foot of the diagram, which sets forth what is at every instant the surplus of supply over demand. To enable the accumulator receiving this variable flow to deliver a fairly regular supply to the turbine, without allowing any of the steam to pass to waste, the accumulator must be large enough to absorb and give out again once in every minute all the heat contained in over a ton weight of exhaust steam, which means that the accumulator must contain over 80 tons of water.

Fig. 429 shows the most recent form of Rateau accumulator, which is provided with a back pressure valve in the exhaust pipe to prevent any possibility of the engines sucking the water back into their cylinders if they continued to run after steam from the boiler is shut off; an escape valve, to allow of an escape of any excess of steam; water float and overflow valve, to maintain a constant level of water; and baffle plates, to ensure thorough circulation of the water, and to prevent it finding its way into the turbines along with the steam.

Plate xxxiii. shows the installation of exhaust turbines at the Hallside Steel Works of the Steel Company of Scotland, fig. 431 being an elevation, fig. 432 a ground plan, and figs. 433 and 434 cross-sections of the buildings. This plant deals with about 40,000 lbs. of exhaust steam per hour, consisting of the exhaust from the cogging mill engine, finishing engine, two small engines, and two steam hammers. There is provision for admitting live steam in the event of the large engines having to stand for any length of time. The turbines are of the Rateau impulse type, and the electric generators by Siemens Brothers, Ltd., supply direct current.

Mixed Pressure Turbines.—When the period of total cessation in the supply of the exhaust steam exceeds ½ to 2½ minutes, according to the size of the unit, the period is bridged over by taking live steam from the boilers. This may be done either by passing this steam through a reducing valve direct into the exhaust turbine, or by admitting it first to a high pressure turbine, usually coupled to the same spindle as the exhaust turbine, and exhausting into it. The latter arrangement is rather more expensive in first cost, but more economical in steam consumption. An exhaust turbine which would consume 35 lbs. of exhaust steam per electrical horse-power per hour would require 33 lbs. of live steam at 140 lbs. pressure expanded in a reducing valve to the usual exhaust pressure, or 19 lbs. if expanded in a high-pressure turbine to the same pressure, and thence discharged into the exhaust turbine, assuming the vacuum to be not less than 27·5 inches with the barometer at 30 inches. By means of suitable arrangements of

[To face p. 685.]

PLATE XXXIII.

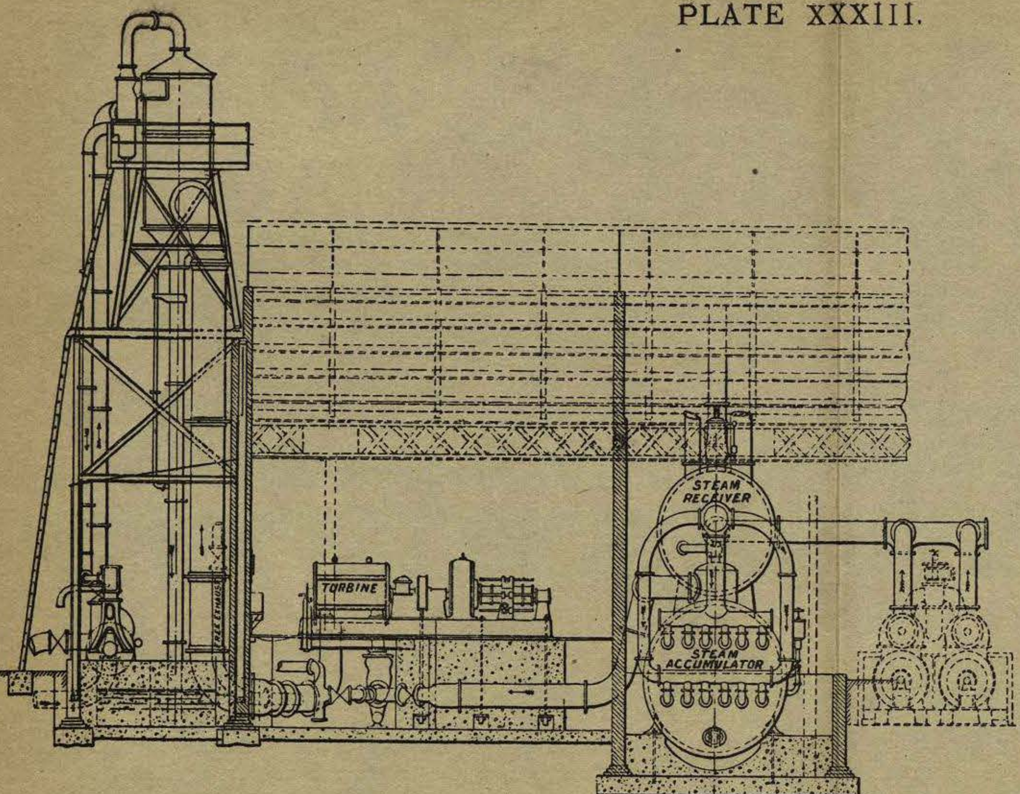


Fig. 431.

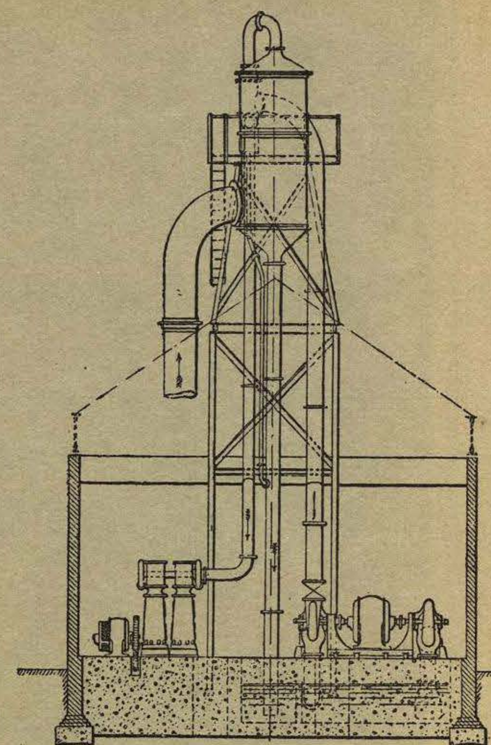


Fig. 433.

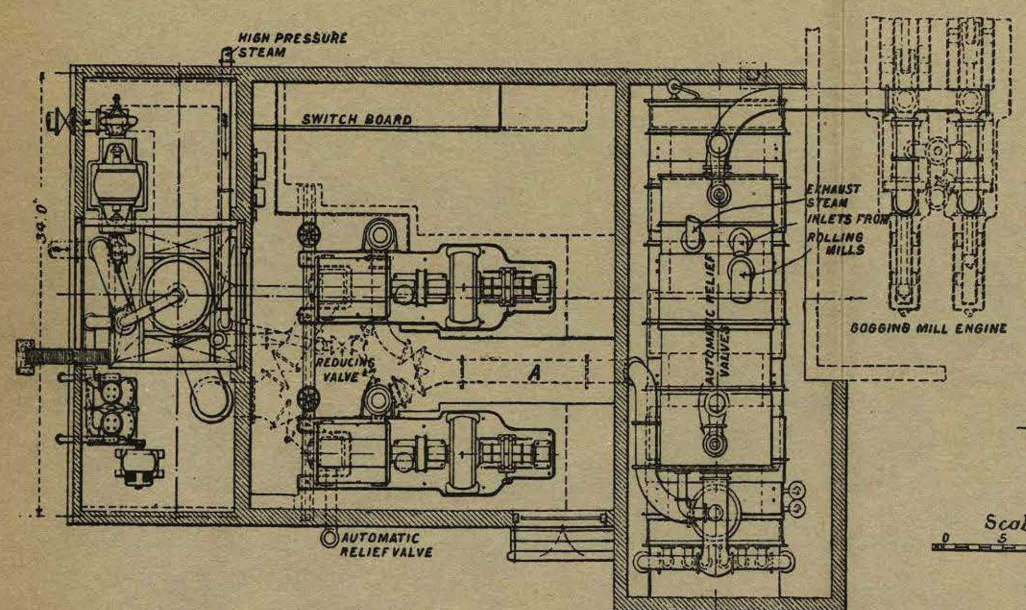


Fig. 432.

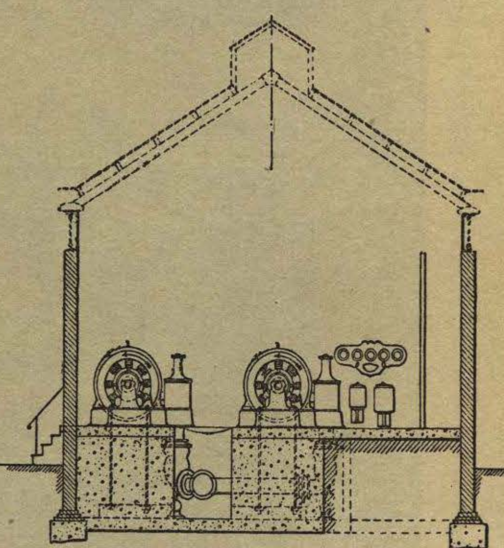


Fig. 434.

valves controlled by the governor, the turbine can be run by exhaust steam only whenever the supply of that alone is sufficient for the purpose, drawing on the live steam to make up a portion or even the whole of any deficiency in the supply of the exhaust from the engines.

Economy due to the Use of Exhaust Turbines.—The additional power obtainable from the exhaust steam cannot very well be applied directly to driving rolls, because the speed at which the blades of the turbine must travel necessitates the spindle of the turbine making from 1,500 to 3,000 revolutions per minute, if the size of the turbine is to be kept within practical limits. This speed, while scarcely suitable for driving a mill, is very well suited for driving electric generators, and the current produced is easily distributed to small electric motors for driving live rollers, shears, cranes, and other subsidiary machinery originally driven by small steam engines. The distribution of steam, through long ranges of steam pipes, to these small engines scattered about a works involves serious loss by condensation, and much trouble to keep steam pipes and engines in decent repair. Moreover, the small engines use such fabulous quantities of steam—40 to 60 lbs. per horse-power when new, rising to four or five times as much when worn—as to have caused their replacement by electric motors in many works, even when a central electric generating station had to be put down expressly to drive them. When the current can be generated from exhaust steam there can be no question as to the economy of replacing small steam engines by electric motors.

Though the speed of revolution of a turbine would seem unsuitable for driving a rolling mill, yet there is at the Calderbank Steel Works a 28-inch three-high plate mill of the Lauth type, driven by a Parsons' exhaust turbine of 750 H.P., worked by the steam exhausted from engines which are driving other mills. The mill is coupled directly to a shaft carrying a flywheel 23 feet in diameter, weighing, with its shaft, nearly 100 tons. The speed of the turbine, which makes 2,000 revolutions per minute, is reduced to that of the mill in two steps, the intermediate shaft running at 375 revolutions per minute. The gearing is steel with machine-cut, double helical teeth lubricated by jets of oil under pressure.

This mill will roll down 30 slabs per hour, and produce plates up to 6 feet wide by 60 feet long, down to $\frac{3}{16}$ inch thick. Occasionally as much as 4,000 to 5,000 H.P. has momentarily been absorbed by the rolls. The combination seems to have given every satisfaction.

The quantity of power obtainable from exhaust steam is considerable, and in practice may range between 50 and 90 per cent. of that given out by the engines from which the exhaust steam is obtained, according to the economy with which such engines are working. In certain extreme cases, where engines, being too small, are so overloaded that they cannot expand the high-pressure steam appreciably, and must discharge it at half the pressure at which they receive it, the turbines could actually develop more power than the engines whose exhaust steam was employed to drive them.

In any case passing the exhaust steam from reversing engines through an exhaust turbine on its way to a condenser affords far more power than passing the same steam to the condenser direct, which only adds from 15 to at most 20 per cent. to the power exerted by the engines, depending on the circumstances under which they are working.

The piston engine can best utilise that portion of the heat contained in steam at high pressures, but, owing to the loss involved by alternate heating and cooling of the cylinder, cannot economically employ that at low pressures,

where a small fall in pressure is accompanied by great variation in temperature, and the surplus heat has then to be thrown away in the condenser. But in the turbine, which is handicapped at high pressures by leakage past the tips of the blades, which must not touch the casing in which they revolve, the flow is in one direction only, so that there is no alternate heating and cooling, and the steam passes through at such a high speed that its volume is a matter of comparatively little moment. It consequently pays to carry the expansion to the utmost limit in the case of the turbine, which makes best use of the heat contained in steam at low pressure, and is, therefore, very dependent upon the degree of vacuum in the condenser, a very slight difference in the vacuum, which would scarcely be felt in the case of a piston engine, having a most detrimental effect in the case of a turbine.

In these days when the Steel Works depend upon the blast furnaces to supply them with molten pig for use in the Bessemer and open hearth furnaces, the two departments have become so mutually interdependent that blast furnace gas is sometimes used to heat the boilers driving the rolling mills, which return the exhaust steam to work turbine blowers to drive the blast furnaces. The development is a very important one, which is likely to extend; but the details of blast-furnace equipment are outside the scope of the present work.

Economy due to Compounding.—When the boiler pressure employed is over about 60 lbs. on the square inch in the case of condensing engines, or 130 in non-condensing engines, so as to make it advisable to expand the steam more than fourfold, there is considerable further economy obtainable by the use of compound engines in which the steam is first expanded in one cylinder, and then passed into a larger cylinder, and still further expanded. The saving in fuel due to compounding in the case of a condensing engine will generally be from 20 to 30 per cent., and in a non-condensing engine 15 to 20 per cent. With boiler pressures of over 150 lbs. a triple-expansion condensing engine, in which the steam is passed through three cylinders in succession, may be used with advantage when the engine is required to run in one direction only. The triple-condensing engine, with a boiler pressure of 165 lbs., will use about 17 per cent. less fuel than a compound condensing with 100 lbs. pressure.*

The economy of the multiple-expansion engine is due to the fact that steam from the boiler is admitted only to the small high-pressure cylinder, and is then expanded further through the succeeding cylinders. This limits the power obtainable from the engine to what can be got from the volume of steam which the small high-pressure cylinder can contain. A simple engine of the same average power would have one large cylinder, nearly the same size as the large low-pressure cylinder of the compound or triple engine, but the steam would be cut off early in the stroke, and the expansion continued in that cylinder; and merely by giving a later cut-off, and so

* It should be clearly understood that in the statements made on pp. 678 to 687, as to the saving in steam obtainable by using it in various methods, only the nett weight of steam delivered in a reasonably dry condition at the stop-valve of the engine is given, and is for engines running continuously in the same direction. More water than this must be always evaporated in the boilers, to make up for that which is condensed in the pipes between the boilers and engines, the amount of which will vary according to the length of the pipes, and the degree of protection they are afforded against cold. Losses from this and similar causes will be much the same, whether the engines are running or standing, and form a constant source of loss, indefinite in extent, which must not be lost sight of, nor must it be forgotten that there is inevitably some steam wasted every time an engine is reversed.

admitting steam at full boiler pressure for the full length of the stroke, the power obtainable from the simple engine is limited only by the volume of steam which this large cylinder can contain. While the simple engine, therefore, loses in economy of steam, it gains enormously in ability to meet any sudden demand for a great increase in power. The ability to meet this sudden demand is of less importance in the case of an engine running continuously in one direction where power equivalent to that given out in from 4 to 8 complete revolutions of the engine can be stored in the flywheel to meet sudden fluctuations in demand, but it is absolutely essential in a reversing engine. It is on this account that several of the early compound non-condensing reversing engines did not give satisfaction, and in more than one case have been either altered to, or worked as, simple engines.

The pressure on the piston of an engine is, at the commencement of its stroke, practically that of the steam in the boiler, but if steam is cut off at an early point, it expands down to a pressure which, towards the end of the stroke, is very low, so that the pressure available for starting the engine from a state of rest is much greater than the mean pressure on the piston. In a compound engine, however, in which the cut-off in all cylinders must naturally occur later than in a simple engine, the initial pressure on each piston is so little greater than the average that the engine starts much less promptly. To cure this defect starting valves have been sometimes provided to admit the full pressure of steam from the boiler direct on to the low-pressure pistons of compound engines. This involves additional levers for the driver to handle, only partially corrects the sluggishness in starting, and to some extent increases the consumption of steam.

To avoid these inconveniences a throttle valve is now placed between the high- and low-pressure cylinders, by which the steam escaping from the high-pressure cylinders towards the end of the run, when the power required is least, may be stored up in the receiver between the high- and low-pressure cylinders, thus providing sufficient pressure on the low-pressure pistons to ensure rapid starting. The Rottmann arrangement secures the same result by fitting the low-pressure cylinders with a variable expansion gear. In either case the rod actuating the valve for banking up the pressure in the low-pressure cylinders is coupled to the handle working the throttle valve of the high-pressure cylinders, and both being worked by one lever their movements are carried out with a certain degree of mutual relation to each other.

Messrs. Ehrhardt & Sehmer's tandem compound-reversing engines have the piston valves controlling the high- and low-pressure cylinders attached to the same valve stalk, and driven by the same link motion, but the steam admission ports of the low-pressure cylinders are so proportioned as practically to cut off the steam from the low-pressure cylinders, while still admitting it to the high-pressure cylinders, when the engine is linked up. Thus steam is stored in the receiver between the cylinders, and the engines slowed down towards the end of the run by the cushion of steam opposing the high-pressure pistons, the volume of steam so stored providing a good pressure on the low-pressure pistons to start the engines promptly in the opposite direction immediately they are reversed.

Having regard to the high steam pressures now available, particularly where condensers are employed, compound reversing engines, fitted with some such arrangements as are outlined above, have a better chance of useful employment in the future than they have had in the past.

Compound reversing engines, however, are costly machines to instal and maintain, particularly when they have three high- and three low-pressure

cylinders, as have some Continental engines, and the simple three-cylinder engine supplying an exhaust turbine is so simple, cheap, easily handled, and economical an arrangement, that compound-reversing engines are not likely to be much used in the future in this country.

Handling Reversing Engines.—When first reversed, an engine needs all the steam that can be thrown against it to pull it up promptly, start it running in the opposite direction, and supply the acceleration necessary to get quickly up to its full speed, but this once attained the supply of steam must instantly be reduced in some way or the engine will run away, and towards the end of the run must be shut off almost entirely. The driver, who holds the reversing lever in his right hand, and adjusts the throttle valve with his left, can control the power and speed either by reducing the initial pressure with the throttle valve, keeping the cut-off constant, or by linking up the reversing gear, so cutting off the steam earlier in the stroke, but keeping the initial pressure constant, or by a combination of both methods.

Reducing power by the link motion, when running at light powers and high speeds, is much the best for two reasons. First, high initial pressure and an early cut-off reduce the consumption of steam during the high-speed light-power period of running by nearly one-half; and secondly, by linking up the reversing gear the exhaust port is closed earlier and earlier in the stroke as the speed increases, confining more and more steam in the cylinder, so forming a steadily increasing cushion wherewith to bring the reciprocating masses quietly to rest, materially reducing shocks and wear and tear. The ordinary reversing gear is an admirable contrivance for doing this.

Drivers do not appreciate a method of working which requires constant independent adjustment of both levers, and are apt to regulate the speed with the throttle only, and use the link motion merely for reversing. To meet this difficulty, Messrs. Davy Bros. and Mr. E. Crowe couple the reversing link and throttle valve together, and work both by means of one lever.* When this lever is in the middle position the throttle valve is entirely shut. Pushing over the lever to its fullest extent in either direction throws the throttle valve wide open, and gives the latest cut-off, which ensures the most rapid possible starting and acceleration of the engine; when the speed of the engine reaches the desired point the man pulls the lever back, thus reducing the cut-off, but admits the full boiler pressure, the cut-off being effected earlier as the man brings the lever in, until a point is reached when it is necessary that the throttle valve also should commence to close to slow down the engine preparatory to reversing.

A somewhat similar arrangement is fitted by Messrs. Ehrhardt & Sehmer to their reversing engines.

By a recent contrivance of Messrs. Galloways the driver is compelled to use his steam in the most economical possible manner—that is, with full boiler pressure, but cut off early in the stroke—while the mill is working. When the reversing lever is in the middle position the throttle valve is held down on its seat, but when the driver moves this lever into a position approaching its extreme travel in either direction, the throttle valve is slightly raised, and the engine turns slowly and steadily with steam of reduced pressure, cut off late in the stroke so long as the mill is running empty. Immediately the piece enters between the rolls, the driver pushes the reversing lever hard over, which throws the throttle valve wide open, and the engine jumps to full speed exerting its maximum power. The speed is controlled by the driver drawing back the reversing lever, so

* English Patent No. 25,033, 1905.

cutting off the steam as early in the stroke as may be necessary for that purpose, but the throttle valve remains wide open until it is released by the lever being brought again into the central position at the end of the run.

Engine Details.—There are such a number of excellent books published on the construction of steam engines, to which the student may refer, that it is needless to write at length on this point. Suffice it to say that, speaking generally, in England piston valves are usually preferred on account of their simplicity, on the Continent double-beat drop valves are most common, while in America the Corliss engine is the favourite, but for reversing engines the piston valve is almost universally employed all over the world. In all three instances the common slide valve is usually fitted on the smaller engines.

For engines running only in one direction a single crank is most common, but for engines intended to reverse and run in either direction, at least two cylinders coupled to cranks set at right angles to each other are requisite, as a single engine is liable to stop with the crank in such a position that the engine cannot be started again without being first barred round off the "dead centre," involving a serious waste of time.

BIBLIOGRAPHY.

"Economy of Steam in Rolling Mill Engines." By M. Worth. Paper read before Cleveland Inst. Eng., February 27th, 1894.

"Conditions which determine the Choice of a Steam Engine." By John W. Hall. *South Staff. Inst.*, December, 1894.

"The Economical Development and Use of Steam Power in Iron and Steel Works." By E. J. Duff. *West of Scot. Inst. Journ.*, vol. iv., p. 134, 1897.

"German Rolling Mill Engines." *Iron Age*, 1899; June 22nd, *et seq.*

"Central Condensing Plants for Iron Works." By W. H. Roy. *West of Scot. Inst. Journ.*, vol. vii., p. 19, 1899-1900.

"Central Condensing Plants for Iron Works." By W. H. Roy. *West of Scot. Inst. Journ.*, vol. vii., 1899-1900.

"The Balancing of Rolling Mill Engines." By G. Service. *West of Scot. Inst. Journ.*, vol. x., 1902-3

"The Utilisation of Exhaust Steam for Engines acting intermittently by means of Regenerative Steam Accumulators and of Low-pressure Turbines on the Rateau System." By E. Demange. *Iron and Steel Inst. Journ.*, vol. ii., 1904.

"The Utilisation of Exhaust Steam, &c." By P. J. Mitchell. *West of Scot. Inst. Journ.*, vol. xii., 1904-5.

"Exhaust Steam Turbines." By P. J. Mitchell. *West of Scot. Inst. Journ.*, vol. xv., 1907-8.

"Utilisation of Exhaust Steam in Low-pressure Turbines." By R. F. Halliwell. Paper read before the Rugby Eng. Society, Dec. 17th, 1908.

"Economy and Design of Modern Reversing Rolling Mill Steam Engines." By Eduard Sehmer and Dr. R. Drawe. *Iron and Steel Inst. Journ.*, vol. i., 1910.

"Weitere Versuche zur Ermittlung des Kraftbedarfs au Walzwerken." By Dr. J. Puppe. Published in *Vereins deutscher Eisenhüttenleute*, 1910.

"Exhaust Steam Regenerators." By Charles H. Smoots. Articles in *Mechanical World*, 3rd Feb., 1911, *et seq.*

CHAPTER XXXI.

THE SUPPLY OF POWER—(*Continued*).

(3) Gas Engines.

Natural Gas.—In some parts of the United States, and near the Caspian, gas issues from the ground at pressures occasionally as high as 700 lbs. on the square inch. Analyses of this gas have been given on p. 139, vol. I., of this work. It is an exceedingly rich gas, showing a heating value of 600 to 1,000 B.T.U. per cubic foot, clean and free from sulphur, giving a beautiful clear heat in a furnace, and suitable for use in gas engines. Those interested in the subject of natural gas will find a paper dealing with it, by Mr. Andrew Carnegie, in the *Iron and Steel Institute Journal*, vol. i., 1885, pp. 168-175.

Blast-Furnace Gas.—The blast furnace is a gas producer on a vast scale. For every ton of iron made in it, it discharges from 110,000 to 180,000 cubic feet of combustible gas, the average being about 130,000 cubic feet. The potential heat contained in this gas represents not less than one-half of all the heat obtainable from the coke. This vast supply of potential power and heat was allowed to go absolutely to waste until Budd, of Ystalyfera, in South Wales, in 1845, patented its use for heating stoves and boilers.

Blast-furnace gas has usually a composition by volume lying between the following limits :—

Carbonic oxide, ...	25 to 32 per cent.
Hydrogen, marsh gas, &c., . . .	2 to 5 "
Carbonic acid, ...	8 to 12 "
Nitrogen, ...	54 to 60 "

Its calorific value is from 85 to 125 B.T.U. per cubic foot—usually about 90 to 110 B.T.U.

As a rule, nearly one-half of the gas is now employed to heat the hot blast stoves, and, where steam blowing engines are employed, the balance is consumed in heating the boilers required to drive them; any surplus remaining after this passes to waste, or is utilised for some small subsidiary purpose.

But when the gas, instead of being used to drive steam engines by means of boilers interposed between the furnace and the engine, is used directly in a gas engine, the same amount of work can be accomplished with the expenditure of much less gas, and a considerable margin is then available for providing power for the steel works.

The volume of gas made is nearly one-third greater than that of the air driven in by the blowing engines. The quantity, therefore, is remarkably regular, as also is the quality, providing the furnaces are working regularly, and storage holders are consequently unnecessary.

Cleaning Blast-Furnace Gas.—The mechanical pressure of the blast drives off with the gas as it leaves the throat of the furnace, numerous particles of coke, ore, lime, &c. The coarse pieces are deposited in a dust catcher provided for that purpose, consisting of a tall cylindrical casing with a conical bottom closed by a door. The casing is two or three times