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equipment for a large mill, which consists of a stand of 36-inch cogging rolls, one of 32-inch roughing and one of 32-inch finishing rolls, all arranged on one bedplate, and driven by one reversing motor, as shown in Plate xxxvii., fig. 459. The mill is intended to roll down 4-ton ingots, and to roll 30 tons of rails per hour. When a larger output is required at a later date, an additional motor can be put down to drive a finishing mill separately, some additional generators being added to the Ilgner motor generator set in order to supply it.

The reversing motor, said to be the largest electric motor so far built in this country, is shown in fig. 460, and is capable of giving 8,000 H.P. normal, at a speed of 60 revolutions per minute, and 12,000 H.P. maximum. That is to say, the turning moment is 310 foot-tons normal, and 467 foot-tons maximum. A special arrangement has been made to enable the motor to give a normal turning moment of 405 foot-tons at any speed up to 30

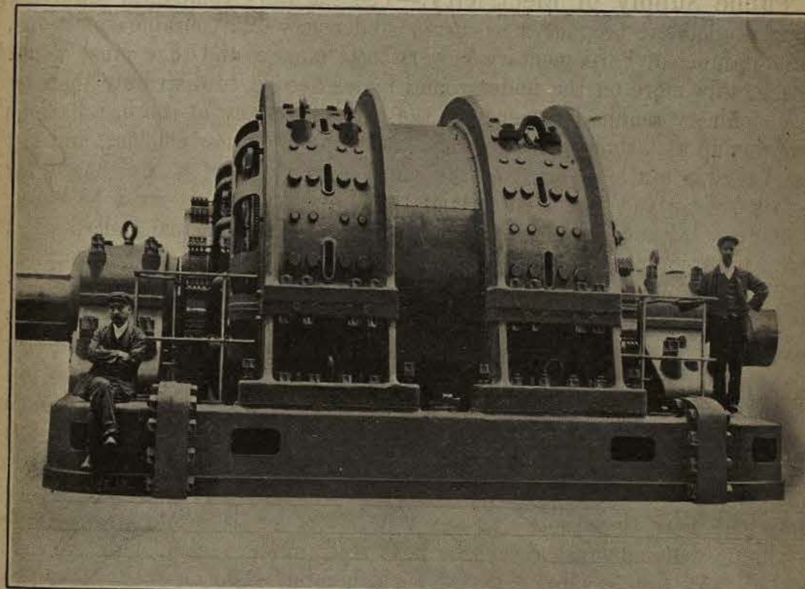

Fig. 460.—12,000 Horse-power Reversing Motor for driving Reversing Rolling Mill.

revolutions per minute, in order to allow for heavy draughting of the rolls in the cogging mill. To provide for finishing rails at a high speed the turning moment is reduced to 132 foot-tons, a large turning moment not being required for the finishing passes.

The Ilgner motor generator set which supplies current to the mill motors, and serves to equalise the demand on the power house consists of two variable voltage generators, and a 1,800 H.P. three-phase induction motor, mounted together on a combined bedplate, and running at speeds between 475 and 380 revolutions per minute. This set is coupled by a flexible coupling of the steel-rod type to a pair of flywheels mounted close together on the main shaft, and carried in two bearings on the sole-plate, separate from the bedplates of the electrical machines. Each flywheel weighs 23 tons, is 12 feet 4 inches diameter, and runs at a maximum peripheral speed of 18,400 feet per minute. The total stored energy in the two wheels is 180,000 horse-power-seconds, and within the range of speed of 475 to 380 revolutions per minute the useful stored energy which can be given up, for equalising variations in the power required, is 64,000 horse-power-seconds. The effect of these flywheels is that when producing the above-mentioned output, the power of the mill motor may rise to 8,000 H.P. or more, while the power required from the power house will not exceed a steady supply at the rate of about 1,350 H.P. It will thus be seen that the above plant has been designed with an ample margin of power to meet with any additional requirements which may arise in the future. The power to drive the mill is generated in a power house at the works by gas engine driven three-phase generators, using blast-furnace gas.

Plate xxxviii., fig. 461, is a plan showing the arrangement of the electrical portions of the plant in their correct relative positions in the works.

Plate xxxix., fig. 462, is a cross-section through the motor house showing the electrically driven fans for cooling the reversing motor which drives the rolls.

Public Supply of Electricity.—The statutory companies supplying electricity have to produce their current under very unfavourable conditions. The obtaining of Parliamentary powers costs money, and they must spend considerably more on the underground mains needed to distribute than on the machinery required to generate the current. Many of the installations were put up at a time when electrical plant was much less efficient, and yet cost twice as much as plant of the same capacity could be purchased for to-day. Wear and tear, depreciation, and interest charges must be based on first cost, although it must be admitted that many municipal undertakings of this nature appear to ignore entirely all such questions.

The public companies, moreover, are under statutory obligations to supply all current their consumers require at any moment, or are liable to fines and the loss of their exclusive rights of distribution. To ensure continuity of supply, they must put down mains large enough to distribute the full supply of current anywhere on the system, and must instal plant enough to meet the maximum demand ever made upon the station, with at least one additional generating unit to serve as a stand-by, because one of these units must sometimes be laid off for repairs. A heavy demand for current may come with very short notice at any time, so boilers sufficient to meet the maximum demand must always be kept ready under steam, with the fires banked. All this to meet a demand which rarely lasts for more than two to four hours out of the twenty-four.

The highest "load factor"—that is, the ratio which the number of units actually generated bears to the number which could be generated if the plant ran continuously at full load—of the Corporation electric undertakings in Great Britain is only 32 per cent., and the lowest 9 per cent.* It is readily seen how these conditions increase the cost of the supply as compared with a central generating station within a steel works. At the Deutscher Kaiser Works, for instance, the load factor was 67·8 per cent. average during the year 1908, and 65·7 during the year 1909.†

Economy of Electric Driving.—The economy obtainable by driving a mill electrically depends entirely upon the cost of the current.

Fully realising that any current, in addition to the small quantity actually sold, can be produced with practically no increase in capital and establishment charges, no appreciable increase in wages, and comparatively little in his fuel bill, the station engineer will usually quote very low prices for current

* *Electrical Times.* Tables of Costs and Records, 1908-9.

† *Stahl und Eisen*, 20th April, 1910.

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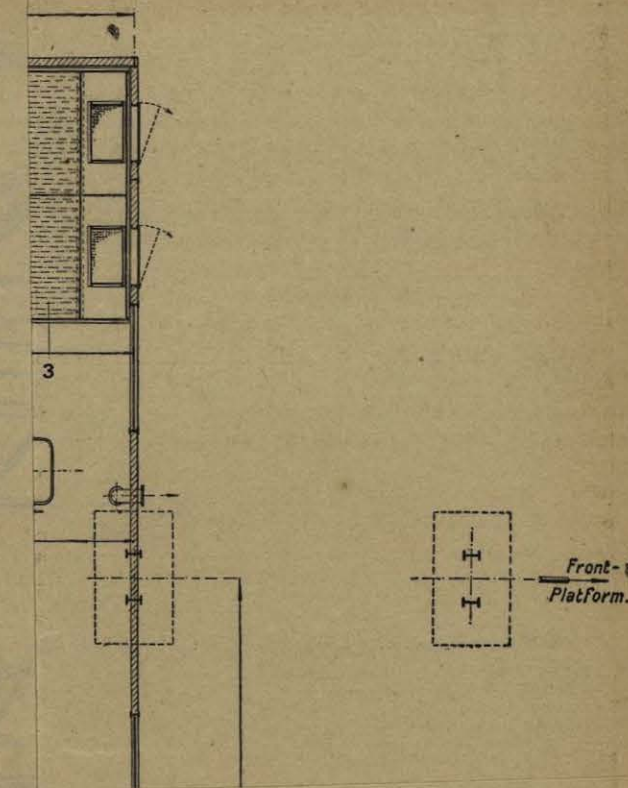

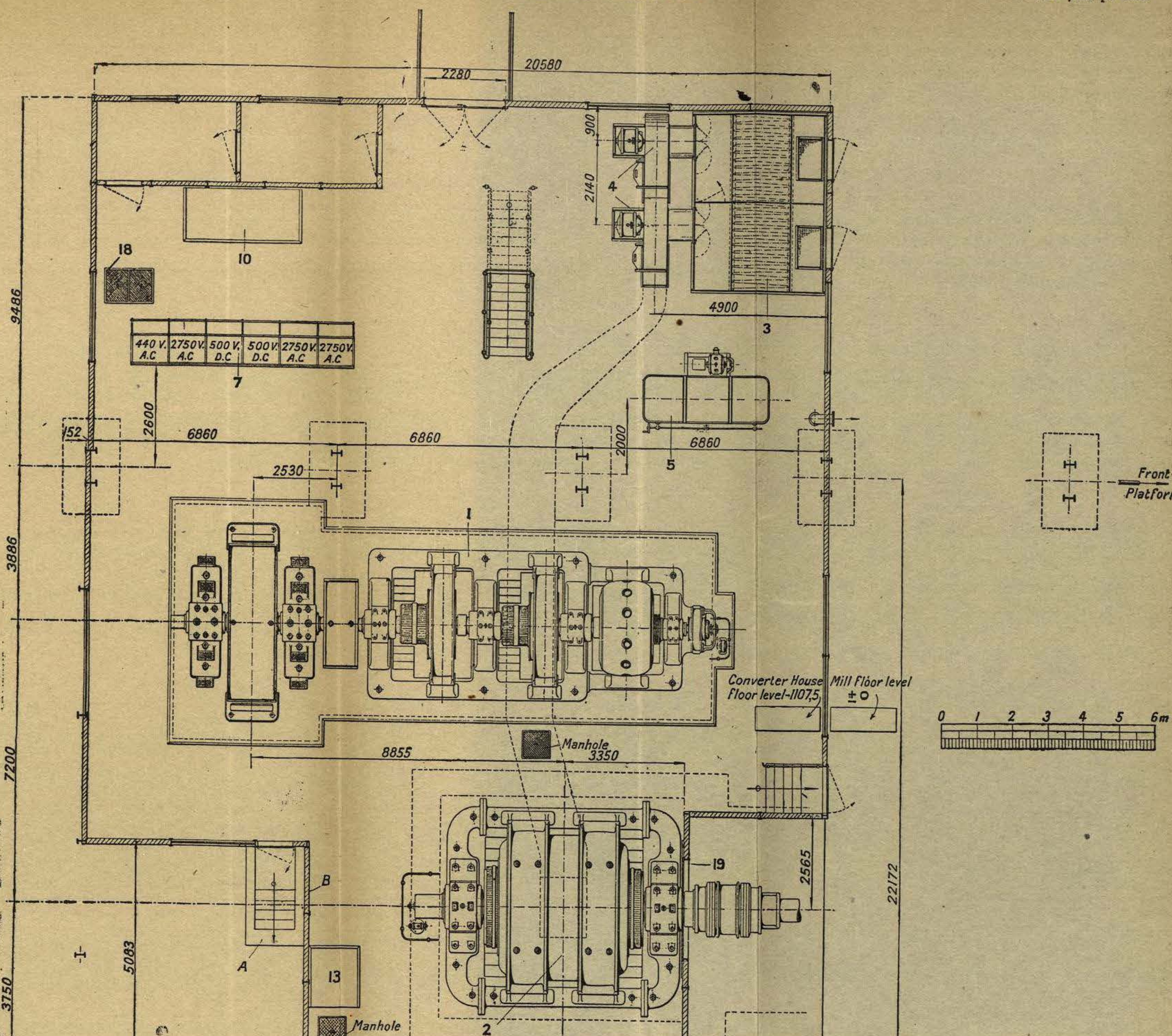

Fig. 461.—Plan showing the Arrangement of the Ilgner Motors, Generators, and the Reversing Motors at Skinningrove Works.

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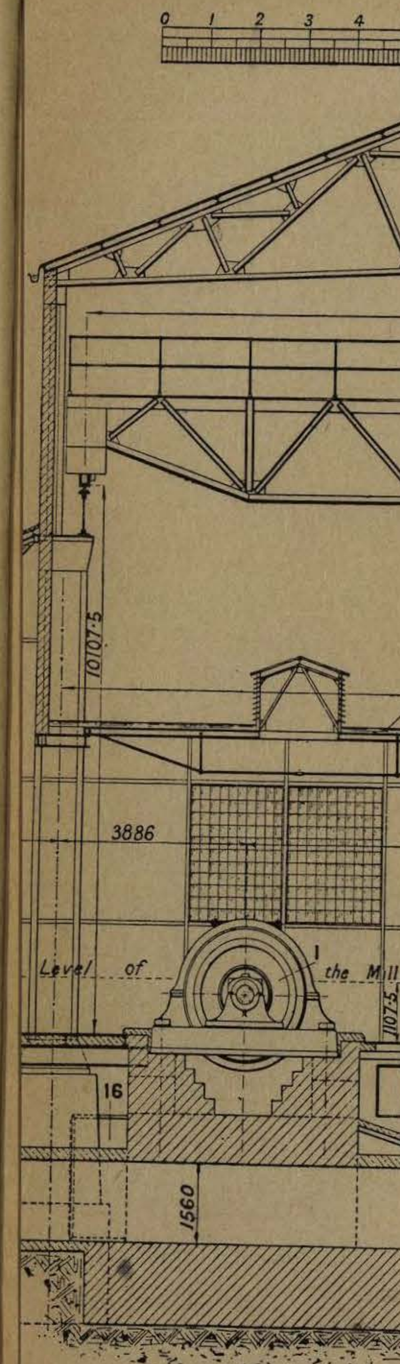

Motor House, showing Fans for Cooling

* *Electrical Times.* Tables of Costs and Records, 1908-9.
† *Stahl und Eisen*, 20th April, 1910.

[To face p. 736.

1. Converter.
2. Mill-motor.
3. Filter with intake ducts
4. Ventilators.
5. Starting and resistance.
6. Relays and accessories.
7. Switchboard.
8. Transformers.
9. High-voltage protective apparatus.
10. Distributing panel.
11. Water resistance.
12. High-tension switchboard.
13. Automatic circuit-breaker.
14. Oil cooler.
15. Oil pumps.
16. Choke coils and transformers.
17. Series-parallel-switch.
18. Opening for transformers.
19. This part of the wall made of iron plate to be easily removable.
20. Ventilator.
21. This roof to be easily removable.

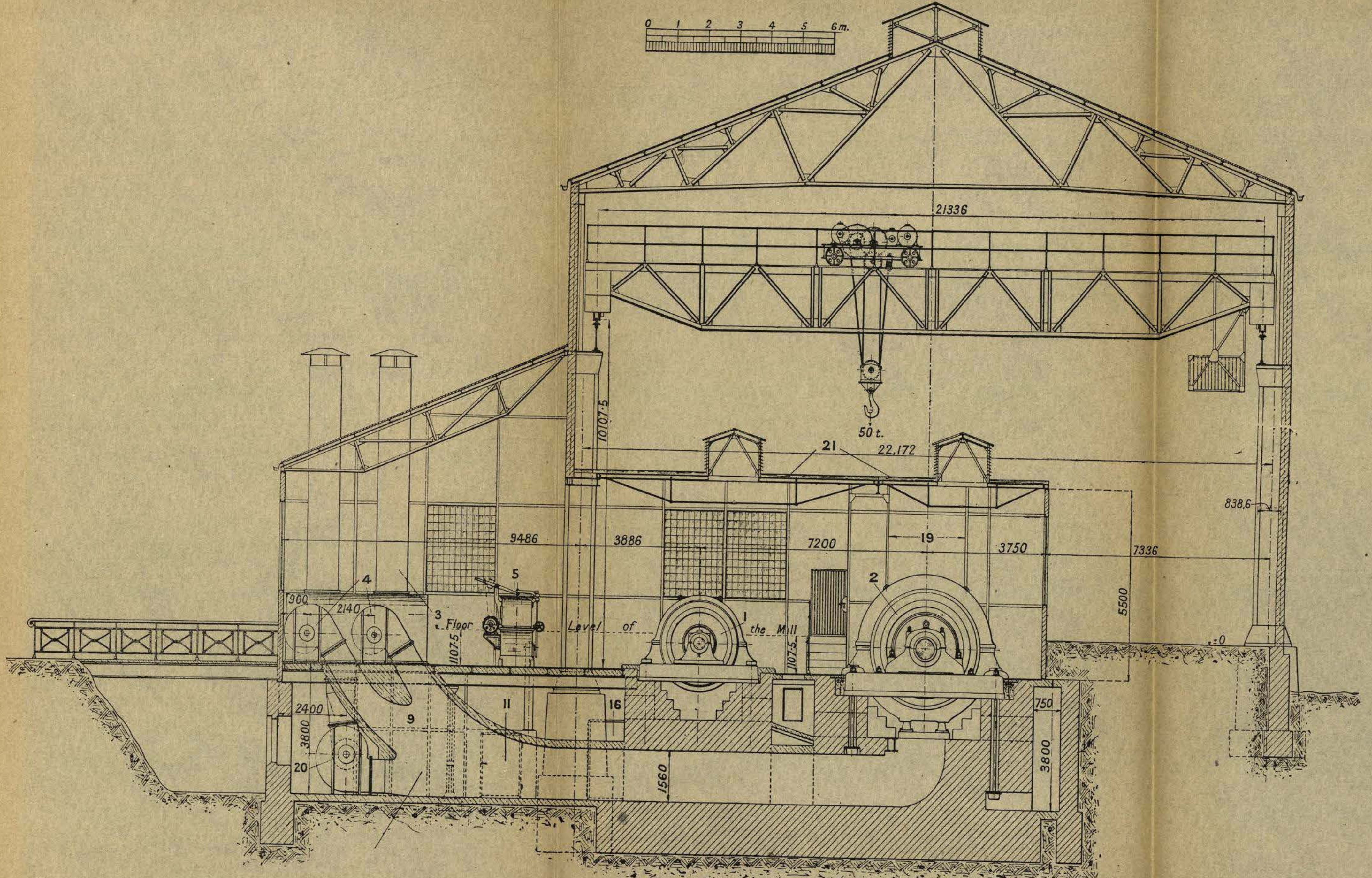

Fig. 462.—Section through Motor House, showing Fans for Cooling the Large Reversing Motors.

to any manufacturer who will take it during the full twenty-four hours, or even during twelve hours in every day.

The owner of a mill requiring little power will find it pay him to purchase his power in this way, rather than provide boilers, which must be periodically laid off for inspection and repair; and in crowded cities he often requires the space the boilers occupy for the purposes of his business. It may even suit him to purchase his power at a price distinctly higher than that at which he could himself produce it, because he can employ the money he would have to spend on engines and boilers to better purpose in his business. If short of capital, he may prefer buying power to borrowing money, which he would have to tie up in fixed plant, because, by buying his power, he gets the use of capital without the inconveniences usually incidental to borrowing it. If his mill runs intermittently, or runs empty during much of the time, he can afford to pay a fairly high price for what power he does use, because the convenience of having it "on tap" in this way is considerable. He also feels that he is paying for only just so much power as he actually uses, though the gain in this respect is not so much as it appears to be, because the charges for current are expressly contrived to discourage such intermittent demands, which is just what the supply companies do not want; nevertheless, the more intermittently his machinery works, the better does it pay him to purchase the power for driving it.

It is only in very exceptional circumstances, such as proximity to such a source of supply as the Middlesbrough Company, that current can be purchased at such a price as would justify driving any but small mills by its means. The question then arises whether it would pay to generate current at a central point within the works, by a steam engine or steam turbine, and use this current to drive several mills scattered about the works, rather than driving each mill by its own engine. If the mills are worked under very variable loads, and yet are numerous enough to ensure a load steady enough to enable one engine to be always working near to its most economical point, it is quite possible that the advantage so obtainable and the avoidance of the losses by condensation in long ranges of steam pipes, would justify the loss involved in electric transmission of the power, which, in such a case, may be expected to be all round about 20 per cent. of the power generated by the central engine. If the new appliances were substituted for existing engines of an old and extravagant type, the gain by replacing them would be correspondingly great. Any such cases would require very careful investigation on the spot of all the individual circumstances before any positive opinion could be expressed as to the advisability of adopting such a course.

It has been suggested that the exhaust steam from the reversing cogging mill engine, if non-condensing, might be used to drive an exhaust turbine, with electric generator, which would supply current to an Ilgner set, which in turn would deliver current to a reversing motor coupled to the finishing mill. It would have to be an exceedingly wasteful cogging mill engine to supply sufficient steam for such a purpose, seeing that the finishing mill almost always takes more power to drive than the cogging mill, and that the electric appliances could only deliver to the finishing mill about 60 per cent. of the power given out by the turbine. Where there are three mills, one might possibly be driven in this way by the exhaust steam from the other two.

But the really important field for profitably using electricity for driving large mills is where gas-driven instead of steam-driven blowing engines having been put in to supply the blast for the blast furnaces, enough gas is set free to drive the mills, so that the power for the purpose is obtained from what is practically a waste product. Driving the mills directly by gas engines is troublesome if the mills are three-high, because such engines have so often to be laid off for a day or two for cleaning. If the mills are to reverse it is impossible. The choice will then lie between employing large gas engines to generate current, not only for miscellaneous purposes about the mill, but for driving the mills electrically as well, through the intermediary of an Ilgner set; and, on the other hand, using the gas to fire boilers, wherewith to drive the large reversing mill engines, leading the exhaust from them to a central station, where it can be utilised in exhaust turbines to generate electric current for working the shears, saws, live rollers, cranes, skids, electric lighting, &c.; for all of which purposes, save the first, electric motors are preferable to small steam engines.

Taking as before 1,000 cubic feet of cleaned blast-furnace gas as required to give 10 H.P. in a gas engine, or if uncleaned to evaporate 1 cubic foot, or 62·4 lbs. of water in a boiler from cold feed, the comparative figures would work out as follows:—

If the efficiency of the electric generators, Ilgner balancing sets, and the mill motors together are 60 per cent., 3,333 H.P. per hour would have to be developed by the gas engines to enable them to deliver 2,000 H.P. mean, or 14,000 H.P. momentary maximum, at the leading spindles of the mills, and about 2,000 H.P. in addition would be required to drive all the accessories, and for lighting, pumping, &c., making a total of 5,333 H.P., necessitating a consumption of 533,300 cubic feet of cleaned gas per hour.

If the mills were driven by steam, the boilers would have to evaporate about 82,000 lbs. of water per hour, consuming in the operation 1,300,000 cubic feet of uncleaned gas, or nearly two and one-half times as much. Of this steam, about 8,000 lbs. would probably be lost in driving the pumps, condensation in steam pipes, &c., leaving 74,000 lbs. for use at the engines to afford 2,000 average horse-power throughout the day. Of this exhaust steam, after allowing for condensation in the exhaust pipes, about 60,000 lbs. would be available for use in the exhaust turbines for generating 2,000 H.P. to supply the current for the various accessories.

Seeing that both gas engines and boilers must be laid off for periodical cleaning and repairs, both spare gas engines and spare boilers would have to be provided, and to cover contingencies, the gas engines would need to be somewhat in excess of the average power to be delivered, or a sudden increase in demand might pull them up.

The plants required in the two cases would then be as follows:—

Gas and Electric Plant.	*Steam and Exhaust Steam Plant.*
Gas cleaning plant to treat 550,000 cubic feet of gas per hour.	Boilers to evaporate 82,000 lbs. of water per hour from cold feed, with feed pumps.
3 gas engines of 1,350 H.P., each directly coupled to—	Add 10 per cent. additional boilers as spares.
3 electric generators, each of 850 kilowatts capacity.	2 three-cylinder reversing engines, capable of giving out up to 7,000 H.P. each.
1 engine and generator as spare.	1 steam accumulator to convert the intermittent supply of exhaust steam from the reversing engines into a continuous supply for the turbine generator.
2 Ilgner balancing sets, to deliver current up to 7,000 H.P. each.	1 exhaust steam turbo-generator of 2,000 H.P., with condensers and air pumps complete.
2 mill motors to take current from the above.	Steam and exhaust pipes and connections.
2 gas engines and generators for supplying current for the cranes, live rollers, &c., the engines to be equal to at least 2,000 H.P. the pair.	
Wiring instruments and accessories.	

In this connection it is as well to correct a mistake found in several papers dealing with electrically-driven rolling mills—namely, that where a reversing engine exerts on an average throughout the whole day 1,000 H.P., and an occasional maximum of 7,000 H.P., it is necessary to put down boilers capable of supplying steam sufficient to produce 7,000 H.P. No doubt the idea is due to the fact that at a public supply station, where the maximum call for current is for electric lighting purposes in an evening, and lasts for some hours, 7,000 H.P. boilers are necessary. But the maximum demand in a reversing mill only lasts for a few seconds, and, therefore, boilers to supply 1,000 H.P. will suffice, as a few figures will show.

A Lancashire boiler, 8 feet diameter × 30 feet long, fed with water at 50° F., will convert this into steam of 150 lbs. pressure by gauge, at the rate of 1 cubic foot, or 62·4 lbs., of water per minute, forming from it 171·6 cubic feet of steam, and absorbing in the process $62{\cdot}4 \times 1{,}175 = 73{,}320$ B.Th.U. per minute. This represents ordinary easy firing; hot feed, picked coal, and heavy firing would enable this output to be double.

But steam can, at any moment, be got out of the boiler for some minutes at a much higher rate than this, because the boiler contains 650 cubic feet, or 40,560 lbs., of water at a temperature of 365° F., and water is the best store-house of heat obtainable; consequently, whenever the outflow of steam exceeds that which the fuel is at the moment producing, the pressure in the boiler falls, and then the amount of heat stored in this large volume of water gives up heat enough to change a portion of it into steam at a slightly lower pressure. For instance, suppose the pressure falls 10 lbs., the temperature of the water will then be 5° F. higher than the corresponding steam pressure, and the water must automatically boil off into steam, until the surplus heat is all expended in producing this change of state from a liquid to a vapour, so that the balance between temperature and pressure may find equilibrium. The amount of heat thus set free to vaporise the water is $40{,}560 \times 5 = 202{,}800$ B.Th.U.; as much as is received from the fuel in $2\frac{3}{4}$ minutes.

But the longest run made by a reversing engine, even if driving a finishing mill, never exceeds half-a-minute, and in the case of a cogging mill, as shown on fig. 430, only occupies four seconds. In electrical phraseology, the boiler is a large storage battery able to withstand rapid discharges, and a record of the pressure within it would have much the same appearance as the lower line in the diagram (fig. 449) for the boiler stores, or gives out energy in the same way as the flywheel of an Ilgner set.

The combined gas and electric plant would be considerably the more costly of the two. The interest on this additional outlay, together with the annual sinking fund to repay it, the additional allowance for wear and tear, and the cost of washing the gas (which is usually put at one farthing per 1,000 cubic feet in this country) has to be set against the value of the gas saved.

What is the real value of the gas saved to the concern depends upon the use they can put it to. Its low flame temperature, and comparatively slow combustion, due to the absence of Hydrogen and of Hydrocarbons, make it an ideal gas for driving gas engines, but these same conditions, particularly the absence of Hydrocarbons, which render the flame non-luminous, and so reduce its radiating power, render it much less satisfactory for heating furnaces. The price put upon it in different works appears to vary considerably. The blast-furnace department can rarely find for it any customer except the steel works, which looks on it as a waste product, which ought to be supplied to them at a nominal charge; while the blast-furnace manager, who is using it to blow his furnaces and heat his stoves, thinks he ought to be paid for it what it would cost the steel works to make an equal volume of producer gas, which is not equitable, as 1,000 cubic feet of blast-furnace gas are only as efficient for heating furnaces as about 650 cubic feet of producer gas, and he cannot understand why the steel works should hesitate to spend large sums in capital to enable them to use it for driving the mills.

When both departments are parts of one concern, the value to be put upon the gas is sometimes considered as a mere question of book-keeping, with the idea that if the price is too high the blast-furnace department will get the profit, and if too low the steel works will benefit. There are considerable objections to looking at the question in this way, and it renders it difficult for the management to decide precisely what amount of capital it is justified in spending, in order to make use of the surplus gas.

The most reasonable way would seem to be to value the gas in terms of the coal which it is capable of replacing under any given circumstances. Seeing that 1,000 cubic feet of uncleaned blast-furnace gas can evaporate a cubic foot of water into steam of 150 lbs. gauge pressure, which would require about 10 lbs. of ordinary unscreened boiler slack, 1,000 feet of such gas may be said to be worth, for this purpose, $\frac{1}{224}$ of a ton of slack. The same volume of gas, if equal to 650 feet of producer gas, which would be produced from $\frac{1}{200}$ of a ton of screened nuts, such as are used for the producer, settles its value for heating furnaces. Its additional value if cleaned for either of these purposes is a question on which opinions seem to differ widely, and as to which very little experimental data exists at the present time. It is very doubtful, however, if it would really pay to clean the gas for either of these purposes.

In conclusion, the author is glad to take this opportunity of expressing his indebtedness to Mr. C. A. Ablett for much valuable assistance in the preparation of the information on electrical matters contained in this chapter.

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