20 March, 1917.

Sir MAURICE FITZMAURICE, C.M.G., President,
in the Chair.

(*Paper No. 4197.*)

"The New Electric Power-House at Birchills, Walsall."

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Walsall, a municipal and parliamentary borough in Staffordshire, is about 8 miles by rail from Birmingham and has a population of approximately 100,000. It is one of the chief centres of the leading hardware manufactures in the Midlands, and has a considerable number of metal-industries.

In the early days of electric lighting, the Corporation of Walsall acquired parliamentary powers to supply electricity to the Borough, and a small generating-station was erected and completed in December, 1895, on a site adjacent to the Corporation gasworks, in Wolverhampton Street, Walsall.

The original system of generation and supply may be briefly described as direct-current generation at 2,000 volts, transmission at the same pressure to sub-stations, and conversion there, by rotary transformers, to 105 volts, with two-wire distribution to consumers. This system was first installed at Oxford and a few other towns in this country, but was never adopted generally.

The original plant consisted of two Lancashire boilers 7 feet 6 inches in diameter and 30 feet long, supplying steam to two small vertical, compound engines, direct coupled to dynamos of about 120 kilowatts capacity, and the requisite switch-gear and accessories. Water-tube boilers and steam dynamos of the same type were added from time to time until 1912, when, on the advice of the Borough Electrical Engineer, then Mr. A. S. Barnard, Assoc. M. Inst. C.E., it was decided to adopt an alternating current, three-phase system for future extensions, and two small steam turbo-alternators were installed. But even after this the original system still had to be relied on for the bulk of the supply, and owing to the rapidly increasing demand, particularly for power, the conditions of working became more and more difficult and unsatisfactory, until 1913, when the Author was asked by the Corporation to advise on the provision of an adequate and efficient supply of electricity for the borough. Complete investigations were then made as to the practicability of increasing the Wolverhampton Street generating-station; in the result the Corporation was advised that this could not be done efficiently, and that the site in Wolverhampton Street was lacking in the principal essentials of an electric power-station of modern design.

Inquiries to determine the probable demand for electricity indicated that, given an efficient supply in the Walsall area, at reasonable prices, a demand for 3,000 to 4,000 kilowatts would be developed in the near future, and that from the nature of the various industries, a power-factor of about 80 per cent., and a load-factor of 25 to 30 per cent., could be confidently anticipated.

It was decided therefore that the most suitable sizes of electric generators would be units of about 4,000 kilowatts capacity, and the Corporation was advised that a new power-station should be built for three such units, thus providing for a total capacity of 12,000 kilowatts. The Corporation adopted this advice and took steps to acquire a suitable site, but in view of the old colliery-workings beneath all the available sites in the district, the possibility of subsidence had to be considered, and Mr. S. L. Thacker was called in to advise the Corporation before one of three proposed sites was definitely selected.

After making the necessary investigations, Mr. Thacker reported that these three sites were in the same drainage-area, and that there was conclusive evidence that the old colliery-workings thereunder were completely waterlogged. The last record of these workings was dated 1876, and Mr. Thacker came to the conclusion that the mine goaves had settled and that all subsidence, due to mining operations, had quite ceased; also that there was no likelihood of future subsidence, unless the mines were drained, or the water-level was materially altered by pumping, but that should this happen there would be considerable risk of disturbance of the goaves, and further subsidence would probably take place. He considered, however, that the latter contingency was exceedingly remote, as in 1900–1903, when a serious attempt was made to unwater these mines, in order to work the bottom coal, the pumping proved to be so excessive that the venture ended in failure with heavy financial losses. There was, therefore, but little likelihood of any future attempt to open up the old collieries in this district.

Having regard to the foregoing, the Corporation purchased several acres of land at Birchills, the governing factor in the selection of this site being that it is on the west bank of the Essington and Wyrley Canal, from which water for condensing and boiler-feed purposes could be obtained. Also the site is adjacent to a branch of the Midland Railway, whose consent to a siding was given, thus providing for transport of coal and materials by rail, as well as by water.

In recent years several Papers have been read, and discussions have taken place, regarding the economy which may be effected in the production and distribution of electricity by the concentration of plant in power-stations of large capacity, with long-distance transmission to consumers. The ultimate limit beyond which no appreciable advantages would accrue by reason of such concentration of plant has been taken at 40,000 to 50,000 kilowatts, but such ultimate capacity would be governed largely by the length of the transmission-mains necessary to serve any particular area of supply. One of the objects of this Paper is to show that a power-station of 12,000 to 16,000 kilowatts capacity can be so designed as to produce electricity at such a low cost that economy in production due to further increase of capacity is not as considerable as has frequently been assumed. Whilst it may be admitted that the costs of production will decrease, to a limited extent, as the plant-capacity of a station increases from, say, 12,000 to 50,000 kilowatts, yet in many cases which necessitate the transmission of electricity over more extensive areas in order to secure a larger demand, such decrease in the costs of production would not be sufficient to balance the additional costs of the longer transmission system.

Before describing the works in detail, it may be said that there are special features in the design and type of plant installed therein which have had very beneficial effects upon the cost; to such an extent is this the case that it is claimed that the new power-station at Walsall, although only of medium size, shows by far the lowest cost, per kilowatt installed, of any yet erected in this country.

In the system of generation there is no novelty. The three-phase system (6,600 volts and 50 periods) was adopted not only because it adequately met the needs of the district, but also because electrical plant and apparatus for this periodicity have practically become standardized by the leading British manufacturers, and the advantages of such standardization are obvious as regards design, first cost, and the celerity with which supplementary and accessory plant and apparatus can be obtained.

The general arrangement of the coal-handling plant is shown in Figs. 2, Plate 3. A small dock has been constructed for the accommodation of two barges, and alongside is the coal-storage yard. The coal-weigher with the receiving hopper is at one end of the coal-storage yard and the boiler-house is at the other end, the centre-lines of the boiler-house and engine-room being at right-angles to one another.

At the side of the boiler-house, adjacent to the canal, is a small out-building containing the cold-water tanks, the hot-well, and the water-softener. Adjoining are a mess-room for the workmen and a small workshop. Lavatory accommodation is provided in a separate building containing the usual conveniences and a bath. An inclined approach-road has been made, so that the plant can be delivered at basement level, directly under the travelling crane which has been erected in the engine-room.

The switch annexe is situated on the side of the engine-room opposite the boiler-house, and is arranged to accommodate the switchgear for three machines and ten outgoing feeders. Both the engine-room and the switch annexe have temporary ends to provide for future extensions.

Trial holes showed that the site was covered to an average depth of about 18 feet with pit-mound and refuse. General excavation over the whole site was made to a depth of about 12 feet, with sloping sides, whilst the excavations for all foundations were carried down to virgin soil, which consisted of stiff clay.

The buildings are of steel and brickwork, and although they are not what are generally known as steel-framed structures, the whole of the concentrated loads are carried by steel stanchions. None of the brick walls is of less thickness than 14 inches, which in itself is a sufficient indication that the building is of a substantial character.

Externally the walls are faced with pressed red bricks, and the building, although of utilitarian character, is quite pleasing in appearance.

The boiler-house walls are faced internally with local pressed bricks, fair pointed and lime washed. The floor is of concrete covered with Staffordshire blue bricks. The whole of the boiler-house roof is glazed with wired glass and lead-coated bars, thus providing ample natural light, which enables the plant to be kept in clean condition and good repair. Adequate ventilation is obtained by means of louvers in the roof, side and end walls.

The engine-room walls are tiled to a height of 6 feet, and above that level are faced with pressed buff bricks, fair pointed. The

Author is of opinion that suitably selected buff bricks are more durable for facing engine-room walls, and retain their appearance for a longer period than glazed bricks or tiles. He has found that after 20 years' life there is no appreciable deterioration of buff bricks, whereas white glazed bricks or tiles are not only far more costly, but become stained, chipped, cracked, and unsightly within a comparatively short period.

Natural light for the engine-room is provided by large skylights glazed with wired glass and also by windows in one side wall, and in the permanent end wall of the building. The basement of the engine-room, in which the condensing-plant is installed, is provided with ample natural light through openings left in the engine-room floor. On the side of the engine-room adjacent to the switch annexe the floor is covered with tiles to a width of 16 feet. The remainder of the floor is covered with chequer plating. The basement walls are limewashed and the floor-surface is finished in fine cement concrete.

The coal-storage yard is about 160 feet long and 60 feet wide, and beneath it a tunnel has been constructed from end to end in reinforced concrete.

The coal-handling plant consists of a jib crane, an Avery coal-weigher, and a bucket conveyer. By means of a grab on the jib crane the coal is transported from the barges, lying alongside the coal-storage yard, to the weigher, where its weight is recorded automatically. From the weigher the coal is discharged automatically into a receiving hopper and stationary filler and thence into the buckets of the conveyer. From the stationary filler the runway of the conveyer is carried above the coal-storage yard on steel supports to the boiler-house bunkers and returns beneath the coal-storage yard by way of the tunnel already referred to.

In this tunnel there is a portable filler into which the coal flows from the coal-storage yard above, through shoots fitted with regulating valves. By means of these shoots and the portable filler, coal can be delivered to the conveyer-buckets from any part of the coal-store, and different qualities of coal can be mixed by filling the buckets at different points alternately.

The conveyer is so arranged that coal can be transported from the receiving hopper to any part of the coal-storage yard and from any part of the coal-storage yard to the boiler-house bunkers, or it can be carried direct from the receiving hopper to the bunkers if required.

From the boiler-house bunkers the coal passes through measuring drums and shoots to the hoppers of the automatic stokers, the shoots being bifurcated at the bottom ends, in order to distribute the coal evenly in the stoker hoppers.

The jib coaling-crane is designed for a maximum radius of 40 feet and is proportioned for handling a grab fully loaded with 25 cwt. of coal. Three motions are provided, namely, hoisting, luffing, and sluing, which are effected by a single electric motor of 30 B.HP. The speeds are: hoisting, 85 feet per minute; luffing, 150 feet per minute; and sluing, 1½ revolution per minute. The motor is started without load, and runs continuously in one direction, thereby avoiding the heavy rush of current consequent upon starting or reversing against a load by means of a controller. The motor is geared through Hollick friction-gear to the main driving-shaft, which also runs continuously in one direction, and this shaft is fitted with reversing bevel gears for sluing and luffing, and with a steel pinion for hoisting. The absence of any necessity to make or break electrical contact ensures quick, smooth, and economical operation. The load is lifted by the application of a brake to the gear, and hoisting can be started quite gently and smoothly by the gradual application of this brake. The luffing-gear is so designed and balanced that the load travels in a horizontal direction and at practically a uniform speed, which drops as the jib approaches the maximum or minimum radius, the construction being such that these limits cannot be exceeded. As no work is done on the load when luffing, and the jib is balanced in all positions, the only force to be overcome is the friction of the working parts, the power required being therefore small. Being balanced in every position, the jib has no tendency to run in or out, except under power, and it is not dependent upon the brake, which is only provided to give greater control and to prevent the jib from being moved by a high wind. In operation the distance from the jib-head sheave remains practically constant, so that the load never need be swinging at the end of a long rope, as is the case with the ordinary straight-lifting jib when it is luffed in to the minimum radius. This feature prevents excessive swaying of the load and consequent waste of time.

The factor of safety of the jib crane is based on the ultimate strength of the materials used, and is in no case less than 5 when the crane is worked at its full capacity.

The grab has a flush capacity of 38 cubic feet and a maximum capacity of 45 cubic feet.

The coal-weigher is designed to receive the contents of a full grab, which are automatically weighed and registered, so that the total weight of all the coal that has passed through the scale to the receiving hopper can be seen at a glance.

The conveyer is of the endless-chain and gravity-bucket type, and is arranged to discharge the coal automatically at the required points by means of a tipping device. It is capable of handling 30 tons of coal per hour, with a chain speed not exceeding 48 feet per minute, and is actuated by an electric motor of 10 B.HP. The operating gear is in the boiler-house, and is entirely under the control of the boiler-house staff.

The overhead coal-bunkers, one for each boiler, have a capacity of 20 tons each, and are carried on the roof-trusses of the boiler-house under the centre of the roof span. These bunkers are provided with hopper mouths for the attachment of the measuring drums, which are capable of dealing with small coal in charges of about 2 cwt. Each measuring-drum is provided with a dust-proof casing, a recording counter, valve, and actuating levers, with chains for operation from the firing-floor level.

The main object in the design of the coal-handling plant, as described, was to obtain adequate coal-storage, and, at the same time, to save the considerable expenditure on constructional work necessary to provide for overhead storage-bunkers of large capacity. A further aim was to facilitate the use of coal from any part of the storage-yard, thereby saving deterioration due to ageing, and reducing the risks of spontaneous ignition.

The boiler-house is designed for the accommodation of six units, and covers a ground-area of 5,250 square feet. Each boiler unit comprises a water-tube boiler, with integral superheater, a superimposed economizer, ejector draught plant, a steel chimney, and a mechanical chain-grate stoker.

The six units are in two rows of three at right angles to the engine-room, the overhead bunkers being centrally situated between the rows.

The main steam-range consists of two pipe-lines, one behind each row of boilers, these pipe-lines being connected at the engine-room end of the boiler-house by a main steam-pipe parallel with the engine-room wall and below ground-floor level. Off this latter main the steam-pipe connections are carried to the main turbines. The main steam-range is also connected at the other end of the boiler-house by a cross pipe, thereby forming the equivalent of a steam ring.

As the vertical portions of the steam range are of sufficient length to take up any movement due to expansion and contraction, it has not been necessary to provide special expansion-bends or joints.

An auxiliary steam-pipe range is also provided, with branches to the feed-pumps and to the water-softener and hot-well, in which are fitted steam-nozzles for raising the temperature of the feed-water when required.

The steam-pipe system is efficiently drained through steam-traps into main drain-pipes, which are carried into the tank-room and discharge into the hot-well.

The boiler feed-pumps are situated in the basement of the boiler-house and the exhaust steam from these pumps is carried to a heater for the pre-heating of the boiler feed-water.

The make-up water for the boiler-feed is taken either from the canal or from a town's water tank to the water-softener and after treatment is discharged into a closed hot-well. The condensate from the main turbines is also discharged into this hot-well.

From the hot-well the feed-water flows by gravity through a Lea recorder to the suction side of the feed-pumps and is then discharged through the feed-water heater to a boiler-feed pipe-ring, off which connections are made to the inlets of the economizers. Air-vessels of suitable capacity are fitted on the feed-pipe range and a Crosby water-feed regulator is provided for each boiler.

From the atmospheric relief valve of each turbine an exhaust steam pipe is carried to a main exhaust pipe, which passes along the boiler-house wall and rises outside the building to above the level of the eaves. This exhaust pipe is drained at the foot of the uptake.

The blow-off pipes from the boilers are carried to a main blow-down pipe, which discharges into a sump constructed of mild steel and situated outside the building.

The chimneys, which are of the Venturi type, are erected immediately over the economizers and pass through the boiler-house roof. Adjacent to the base of each chimney is the ejector-draught fan driven by a three-phase motor.

The boilers and economizers are supported independently on steel framework, and the draught plant and chimneys on rolled steel joists.

The boilers, which are of the Babcock-Wilcox steel-cased, cross marine type, have approximately 4,000 square feet of heating-surface, and are designed for a working-pressure of 185 lbs. per square inch. They are fitted with integral superheaters, capable of imparting 260° F. of superheat to the steam raised. The heating-surface of each superheater is 1,468 square feet.

Two of the units are provided with Babcock-Wilcox wrought-steel horizontal-tube economizers, and the other two units with cast-iron horizontal-tube Green economizers. The heating-surface of the economizers is 2,104 square feet each.

The casing of the boiler and economizer consists of wrought mild steel plates, bolted to tee- and angle-bar framework, lined with "calinsulate," and provided with an outer screen-plate, supported with bolts and ferrules, so as to form a space of 1½ inch between the casing and the screen-plates.

The furnace brickwork of the boilers is built throughout with Glenboig firebricks.

Each boiler is provided with a pair of chain-grate stokers, of the Babcock-Wilcox drop-link type, giving a total active grate-area of 140 square feet. The stokers are driven from two lengths of shafting, one on each side of the boiler-house basement. Each shaft is driven through worm reducing-gear by a three-phase motor of 6 B.HP.

In the boiler-house basement, beneath the chain-grate stokers, are situated the ash-hoppers, lined with fire-tiles and provided with ash-doors. The ashes fall through shoots into trucks, which are wheeled away to an adjacent ash-dump.

The fans for the ejector induced draught are of the double-inlet forced-draught type, with full housing casing, divided at the horizontal centre-line, and are driven at a speed of 960 revolutions per minute by direct-coupled three-phase motors of 35 B.HP. each.

Each boiler-unit is designed for a normal evaporation of 26,000 lbs. of water per hour, from a feed-temperature of 100° F. entering the economizer, to steam of 185 lbs. per square inch pressure and a total temperature of 636° F. On high duty each unit will raise 30,000 lbs. of steam per hour, and with natural draught 13,000 lbs. These duties are based upon the use of South Staffordshire, unwashed, slack coal, having an average calorific value of 11,000 B.Th.U. per pound, as fired.

In Appendix I particulars are given of tests of a boiler-unit of the type referred to, tabulated in accordance with the standard form of The Institution of Civil Engineers, and it will be observed that the results obtained show an overall efficiency of upwards of 88 per cent., based on the net calorific value of the coal.

The feed pumps are of the Weir centrifugal type, direct driven by small steam-turbines. Each pump is capable of delivering 8,000 gallons of water per hour against a boiler-pressure of 185 lbs. per square inch. The supply of steam to the pumps is controlled automatically and the pumps adjust themselves to changes in both water and steam conditions.

The space occupied by this type of steam-pump is very small, and being practically dust-proof, the pump need not be installed in an enclosed room, as is desirable with plunger pumps.

The feed-water heater is of the enclosed type, arranged on the delivery side of the feed-pumps.

The steam-pipes from the stop-valve of each boiler-unit to the main steam-range are 7 inches in diameter, the pipes of the main steam-range are 12 inches, and the branch pipes to the main turbines are 8 inches. The auxiliary steam-range is 3 inches in diameter, with 2½-inch branch pipes to the feed-pumps. The blow-off pipes from the blow-off valves of each boiler are 2½ inches in diameter and the main blow-down pipe is 4 inches in diameter.

The exhaust-pipes from the automatic release valves of each turbine to the main atmospheric exhaust-pipe are 20 inches in diameter, and the diameter of the main exhaust-pipe ranges from 20 inches at the smallest part to 30 inches at the largest.

The delivery-pipes from each feed-pump to the main boiler-feed ring are 3 inches in diameter, and the main boiler-feed ring is 6 inches in diameter with 2½-inch branches to each economizer-inlet. The suction pipe from the hot-well to the feed-pumps is 6 inches in diameter with 4-inch branches to the pumps.

The cooling-water delivery- and discharge-pipes for each of the surface condensers are 20 inches in diameter; the condensed-water discharge-pipe from each turbine is 4 inches in diameter and the main-condensate discharge-pipe to the hot-well is 7 inches in diameter.

The whole of the high-pressure steam-piping, the blow-off bends from the boilers, and the boiler-feed delivery piping are of weldless mild steel with wrought-steel flanges to the dimensions of the Engineering Standard Committee's report,

The exhaust-pipes, the main blow-off pipe, the condensed-water discharge-pipes, the condenser circulating-water pipes and the main drain and overflow pipes are of cast iron, with the exception of the main atmospheric exhaust-pipe which is of riveted mild-steel plates for 20 inches diameter and over.

All steam-pipe joints subjected to superheated steam are made with corrugated nickel rings, and other steam- and exhaust-pipes with corrugated brass rings. The water-pipe joints are made with a rubber insertion.

The whole of the valves for the steam-, exhaust- and water-pipes are of the full-way type. All valves subjected to boiler-pressure have cast-steel bodies. On the steam-pipe system the valves and seats are of nickel alloy suitable for highly superheated steam. On the pressure side of the feed-water system the working parts of the valves are of gun-metal. On the water-pipes the valves have cast-iron bodies and gun-metal working parts.

The steam-pipes and feed-pipes are lagged with a cork covering lined on the inside with a plastic magnesia composition, to a total thickness of 2 inches. All flanges are covered with a removable sheet-metal casing, lagged with magnesia composition 2 inches thick. The magnesia composition consists of not less than 85 per cent. of magnesia and 15 per cent. of asbestos fibre.

The general arrangement of the boiler-house and engine-room plant, which is shown in Figs. 1, Plate 3, is in some respects novel; it is one of the first examples in this country of a modern power-station designed and built for the accommodation of the special type of boiler already described. The idea of superimposing the economizer is not new, but previously it had involved a separate superstructure and a kind of three-story arrangement, as at the Greenwich power-station of the London County Council. No such superstructure is required for the self-contained Walsall boiler-unit, and the height of the boiler-house is only slightly more than is necessary for ordinary boilers.

Another important feature of the self-contained boiler-unit is the ease with which it is possible to arrange the heating-surfaces of the boiler and economizer, relative to the superheater, so as to obtain any desired superheat without varying the overall efficiency.

The ejector draught system, which has been adopted, has been but little used in this country. A suction draught of about $1\frac{1}{4}$ inch is produced by a cold-air blast in the chimney of about $3\frac{1}{2}$ inches water-gauge pressure, the chief advantage of the system being that no hot gases pass through the fan and consequently the fan is smaller and its life is longer. Admittedly, the ordinary induced-draught system, in which all the hot gases pass through the fan is more efficient, but on the other hand, ejector induced draught facilitates a more compact design at lower capital cost, and the total power required by the fan does not exceed 1 per cent. of the evaporation of the boiler. Moreover, recent tests have shown that with this arrangement of ejector-induced draught, it is possible to obtain, with the fan shut down, 65 to 70 per cent. of the normal evaporation of the boiler. Induced draught with short chimneys is not only more flexible, but also far less costly than the natural draught of large and high brick or steel chimneys. In fact, with the low-temperature gases now discharged from modern boiler-units, the extreme height of brick chimneys necessary to maintain a sufficient natural-suction draught is such as practically to prohibit them.

The automatic stokers are so designed that any damaged fire-bars can be replaced whilst the stoker is in operation. Their grates have a large total air-spacing and small individual air-spacing for burning small, low-grade coal with a minimum of riddlings, the design of the drop-link being such that the relative motion of the links on the return journey helps to remove any small coal, which might otherwise be an obstruction to the free passage of air.

It can be seen from the plans of the Walsall station that it has been possible to obtain a high concentration of steam-raising plant on a very small floor-space, with ample room in front and around the boilers for easy and comfortable operation. The total steam-raising capacity of the six boiler-units for which the station is designed is 180,000 lbs. of steam per hour. Therefore the total boiler-house area required for this type of plant is, in this case, only 1 square foot per 34 lbs. of steam raised per hour, whereas for land-type water-tube boilers and economizers with brick flues and chimneys on the same level, the steam raised per square foot of boiler-house would not exceed, say, 15 lbs. per hour. Perhaps the following approximate statement of steam raised per square foot of ground-area actually covered by different types of boilers will better demonstrate the advantage of the design adopted at Walsall.

POUNDS OF STEAM PER HOUR, FROM AND AT 212° F., PER SQUARE FOOT OF GROUND-SPACE, FOR VARIOUS TYPES OF BOILERS.

Lancashire boilers with economizers at back and by-pass flues . .	18 lbs.
Water-tube ,, ,, ,, ,, . .	35 ,,
,, ,, ,, and chimney superimposed .	100 ,,

The general arrangement of the Walsall boiler-house plant not only represents the tendency of modern practice, but also indicates the important bearing which this has upon the general and structural design of power-stations. During recent years the advent of large electric generators has led to the general adoption of land-type water-tube boilers, but the rapid development of the steam-turbine, and the small space required for its accommodation, now calls for still further consideration of boiler-house design.

A 4,000- to 5,000-kilowatt turbine requires but little more space than a 1,200-kilowatt reciprocating engine, and therefore greater concentration of steam-raising plant is called for, in order to prevent the boiler-house from considerably overlapping the turbine-house, with all its consequent disadvantages.

The maximum evaporation of any modern boiler depends upon the grate-area which can be placed beneath it; or, in other words, upon the quantity of coal which can be burned effectively on the available area. The space allotted to the grate-area depends upon the size of boiler-unit which may be the most suitable for a particular station, and any hourly capacity may be selected, up to, or even exceeding 100,000 lbs. of steam. Having so fixed the grate-area, it is clear that the greatest concentration must be attained by placing the whole of the steam generating and recuperating plant directly over the grate-area, as has been done at Walsall, by the adoption of self-contained boiler-units. A further advantage of this type of unit is that, owing to its compactness, the lengths of steam-pipe and of pipe-work generally can be reduced to the minimum, thereby saving, not only in first cost, but also in thermal losses and maintenance.

The engine-room will accommodate three steam-turbine-driven alternators, each of 4,000 kilowatts capacity, with the surface condensing-plant in the basement.

The cooling-water for the condensers flows from inlet sumps, situated alongside the canal, to the inlet side of the circulating-water pumps and is discharged from the condensers back to the canal, the discharge-pipes being carried some distance along the tow-path in order to avoid the hot water flowing back to the inlet sumps.

An overhead travelling crane is provided in the engine-room and is constructed to lift a maximum load of 30 tons from the basement level. The crane is provided with three motions, namely, hoisting, traversing, and travelling. The hoisting and traversing motions are operated manually. The travelling motion is operated electrically. The lifting-gear has four speeds, namely, 8 inches, 5 inches, $3\frac{5}{8}$ inches, and $1\frac{3}{4}$ inch per minute. The speed of traversing is 12 feet per minute and of travelling 100 feet per minute.

The turbines work with steam at a pressure of 180 lbs. per square inch and a temperature ranging from saturation to 620° F. at the stop-valve, the normal speed being 3,000 revolutions per minute.

The turbines are of the compound, horizontal, impulse type, the first stage being compounded for velocity and the subsequent stages for pressure. They were built by Messrs. Belliss and Morcom, Ltd. The wheels are of nickel steel, and the moving blades are also entirely of steel. Some of the blades are welded to their root or distance pieces, while others are stampings machined all over. The fixed blading is so designed that all of it can be readily detached from the diaphragms for cleaning or renewal, and it is claimed that this is an improvement on the more usual practice of "cast in" construction, as with the latter it is very difficult to prevent a certain amount of blowing during the casting, and this blowing does not become evident except by machining close down to the blade metal. The fact remains that such diaphragms do become disintegrated, and no doubt this action is considerably assisted by the blades having to be set at an acute angle (about 20°), which does not conduce to stability.

The shaft is of high-tensile ordinary mild steel and the critical speed of the rotor is about 4,000 revolutions per minute. The steam-chest is distinct from the middle casing, and is of cast steel, as are also all the high-pressure valve-body casings.

The governor-valve is of the double-beat, throttle type, but consists of two valves in series, the second being provided for heavy overloads and non-condensing conditions. This valve by-passes the steam to the second stage, but in order to prevent the inevitable and continuous leakage which would otherwise occur (double-beat governor valves never being absolutely tight), an isolating valve is placed in the by-pass valve.

The emergency-valve is of an interesting type, and is made on very much the same principle as the well-known Ferranti steam stop-valve, the diameter at the side or neck being about half the diameter of the pipe. The valve itself is a kind of globe, attenuated into a spindle, at top and bottom, the whole being cut out of a solid piece of steel. This valve is held off its seat by an internal lever, and is provided with trip-gear on the outside. The advantage of a valve of this type is that it only occupies the space of a short length of pipe, and is not a bulky apparatus, as are most valves used for this purpose.

The stuffing-boxes or glands are carbon-packed; so also are the diaphragm-glands. In all cases they are arranged in a semicircular grip (not circular as usual), and the top halves are so attached to the casings that they lift clear and do not have to be pulled to pieces when lifting the top half of the turbine. Also the casing glands can be taken to pieces endwise in the usual way.

The thrust-block is of the Michell type,[1] and is arranged between the bearing and the stuffing-box. It is of the single-thrust design, the small occasional back thrust being taken by a collar at the end of the main bearing. This back thrust only occurs when the turbine is running light after steam is shut off. The normal or front thrust is never very considerable, but is an indeterminate quantity depending on several more or less unknown factors, the chief of which are the questionable prevalence of a perfect pressure-balance on both sides of any one wheel, and the effects of eddy-currents within the cells.

The whole of the governor-mechanism is arranged at the turbine end in an approximately circular casing, and is accessible for

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[1] Minutes of Proceedings Inst. C.E., vol. cxcvi, p. 241.

inspection by moving the end cover. This mechanism is pressure-lubricated throughout.

The governor is of the centrifugal type, driven through worm gearing from the main shaft. An emergency governor is also provided, which is independent of and remote from the main governor. The governor-valves are operated through oil-pressure relays. The main relay is on the dog-lever principle, and the emergency relay acts as a dashpot and closes the valve at a prescribed overspeed, or on failure of the oil-pressure, or by hand. The permanent variation in the speed of the turbine is limited to 3 per cent. between 25 per cent. overload and no load, and the temporary variation is limited to 5 per cent. when the whole load is thrown on or off. The turbine speed can be regulated by hand, or by means of a small electric motor operated from the main switchboard.

The vertical main governor-spindle drives the main oil-pump fitted below in the base-plate, the latter serving as the main reservoir. This pump is of the helical-gear type, and is driven through a flexible coupling, which not only counteracts the effects of expansion, but also facilitates erection and setting. The oil-pump draws through two strainers, either of which can be taken out while the turbine is running, and the act of removing either strainer closes its suction orifice, so that dirt cannot be sucked in.

A motor-driven, auxiliary oil-pump is also arranged in conjunction with the main oil-pump, so that it can take on the whole pumping duty if necessary. The two pumps are controlled by a directing-box for by-passing around either or both the coolers, or for putting either the main or auxiliary oil-pump in circuit. It is remarkable that directing-boxes have been used so little in land work, whereas in marine work they are practically the rule for the distribution of fluids. Certainly a directing-box is a very much more convenient, compact and comprehensible apparatus than numerous separate valves and cocks distributed promiscuously in more or less accessible positions.

Two oil-coolers are provided for each turbine. Water for oil-cooling is taken normally from the main circulating system, but provision is made for an auxiliary pump-supply, and also a town's water-supply, all controlled by a directing-box.

The condenser for each turbine is of the contraflow surface type, with a rotary kinetic air-pump and centrifugal circulating-water pump. These pumps are coupled in line with and are direct-driven by a three-phase motor of 95 B.HP. Each condenser is designed to maintain a vacuum equivalent to an absolute back pressure of not more than 2 inches of mercury when the turbine is operating at full load, and with cooling-water at the maximum initial temperature not exceeding 75° F.

All valves, switchgear, and instruments are so arranged that the operation of the condensing plant is entirely controlled from the engine-room floor.

A steam-pressure recording and indicating gauge is connected with the boiler side of each turbine stop-valve, and steam-pressure gauges are connected to the steam inlet of each turbine and to every alternate stage. Oil-pressure gauges are provided to each bearing. Vacuum-recording and Scane efficiency gauges are fitted to each condenser.

Fournier triplex temperature-recorders record the temperatures of the steam inlet, the cooling-water inlet, and the cooling-water outlet.

Lea recorders are provided for the condensed-water discharge, with indicating and integrating attachments, in the engine-room, so that the steam-consumption of any turbine can be observed at any time, and the total steam consumed can be recorded automatically. A calibrated nozzle and water-gauge is also provided on each condensate discharge in order to check the consumption.

The steam-consumption of the turbines, per kilowatt-hour, with a steam-pressure of 180 lbs. per square inch at the stop-valve, a steam-temperature of 600° F. at the stop-valve, and a cooling-water temperature of 75° F., is shown in Table I, Appendix II.

The alternators, by Messrs. Siemens Brothers Dynamo Works, are of the revolving-field type, and are designed to generate three-phase alternating current at a terminal pressure of 6,600 volts between phases, with a frequency of 50 complete cycles per minute, when working at a speed of 3,000 revolutions per minute.

The full-load output of the alternators is 5,000 kilovolt-amperes, or 4,000 kilowatts when supplying current on a load with a power-factor of 0·8. The alternators are also capable of giving an overload output of 6,250 kilovolt-amperes, or 5,000 kilowatts with a power-factor of 0·8, for a period of 2 hours.

The exciters are of the overhung type, the armatures being mounted direct on the alternator-shafts. They are shunt-wound, multipolar machines, with main and commutating poles, designed for a pressure of 125 volts, and are capable of giving the full excitation-current required by the alternators for an output of 6,250 kilovolt-amperes, without overheating or sparking. With full load thrown off, the rise in voltage of these alternators, at unity power-factor, with a constant field and at constant speed, is approximately

16 per cent., but Tirrell automatic pressure-regulators are provided, which will maintain the terminal voltage, within a variation of not more than 0·5 per cent. above or below the mean working-pressure, under all ordinary variations of power-factor, load, and speed.

The construction of the Siemens alternator is well-known and need not be described in detail. Its more important features are the rotor core, which is a solid forging in one piece with the shaft, the thorough method of securing in position the connections of the rotor ends by means of solid forged steel covers, so as to withstand the heavy centrifugal stresses, and the effectiveness of the winding-supports and method of bracing the end windings of the stator.

Efficient ventilation is ensured by streams of cold air flowing through axial ducts, which are so distributed as to bring the air into close contact with the parts where heating occurs. With this cooling system the air is brought into contact with each lamination, the flow of heat being along the metal of each plate, and it is claimed that this is far more effective than the radial system, where the heat has to pass through the insulating material of the plates and the minute air-spaces between the plates, both of which have much greater thermal resistance than the plates themselves.

The cooling air is drawn from the outside of the engine-room through a dry filter and duct by means of a fan fitted on the rotor of the alternator and forming an integral part with it. The arrangement of duct and filter is such that a wet air filter can be substituted if required.

Tests of the materials used in the construction of the alternators have been made, and also the following:—

(*a*) Losses and efficiencies from light-load tests.
(*b*) Open-circuit, short-circuit, and open loss curves.
(*c*) Oscillograph showing the flux and pressure waves on open circuit.
(*d*) Pressure tests of 13,000 volts on the stator windings and 1,000 volts on the rotor and exciter windings.
(*e*) Balancing and 15-per cent. overspeed test for 15 minutes.
(*f*) Voltage regulation.

The losses and efficiencies calculated from the light-load tests at 6,600 volts and 50 periods are shown in Table II, Appendix II, p. 225.

The machines ran quite smoothly on the overspeed test and on subsequent examination no defects were apparent.

The regulation figures based on the test results were: with constant speed and excitation, a rise in pressure, from full load (6,600 volts) to no load, of 33 per cent. at 0·8 power-factor, and 16 per cent. at unity power-factor.

The extra-high-tension switchgear, which is on the first floor of the switch annexe, is designed for the control of three alternators, of 4,000 kilowatts capacity each, and seven outgoing feeders of 1,500 kilowatts each, including the inter-connecting mains with the old station. The bus-bars are in duplicate, and the two sets can be coupled by means of a non-automatic inter-connecting switch. The Merz-Price balance system for generator-protection is employed, the neutral point of the system being earthed through a special transformer. The synchroscopes are of the rotary type and the voltage is controlled by two Tirrell pressure-regulators.

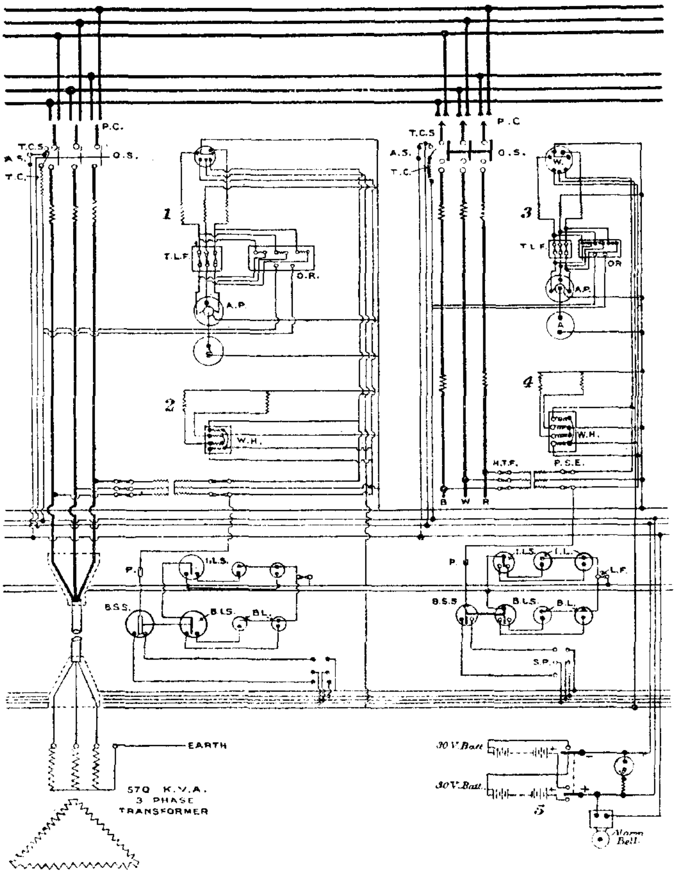
All the necessary apparatus and measuring instruments for controlling and recording the output are provided (*Fig. 3*), pp. 212–213.

The switchgear is of the Reyrolle ironclad type, the special feature of which is the complete enclosure of every conductor in a metal cover and the immersion of the bus-bars, current-transformers, and other live conductors in compound, so that not only is it impossible for anyone to make accidental contact with any part carrying current, but also the necessity of cleaning operations on high-tension work is obviated. Other features are the construction of the oil-tanks in boiler-plate, which will withstand a pressure of 80 lbs. per square inch, the large volume of oil employed, and the comparative lightness of the moving parts of the oil switch. The strength of the tank, the method of suspension (the volume of oil providing a cushion for this purpose) and the lightness of the moving parts, allowing rapid acceleration, are combined to form an oil switch which will operate satisfactorily on heavy short-circuits. The working parts of the gear are supported on cast-iron stands and the oil switch is of the carriage type, provided with plugs which fit into sockets formed in the bus-bars and transformer-chambers. Locking-off doors automatically follow the switch when it is withdrawn and fall across the socket-openings. The working parts of the switch can therefore be inspected quickly and in perfect safety.

The potential transformers and protective devices are also disconnected in a similar manner and are provided with interlocking gear which obviates errors in manipulation or accidental contact with live parts.

The low-tension switchboard for controlling the supply of electricity to the station auxiliaries and for lighting the works is on the ground floor of the switch annexe and is provided with the necessary meters. The low-tension supply is taken from two 625-kilovolt-ampere Westinghouse transformers, ratio 6,600/375 volts, erected in the basement of the switch annexe.

Fig. 3.

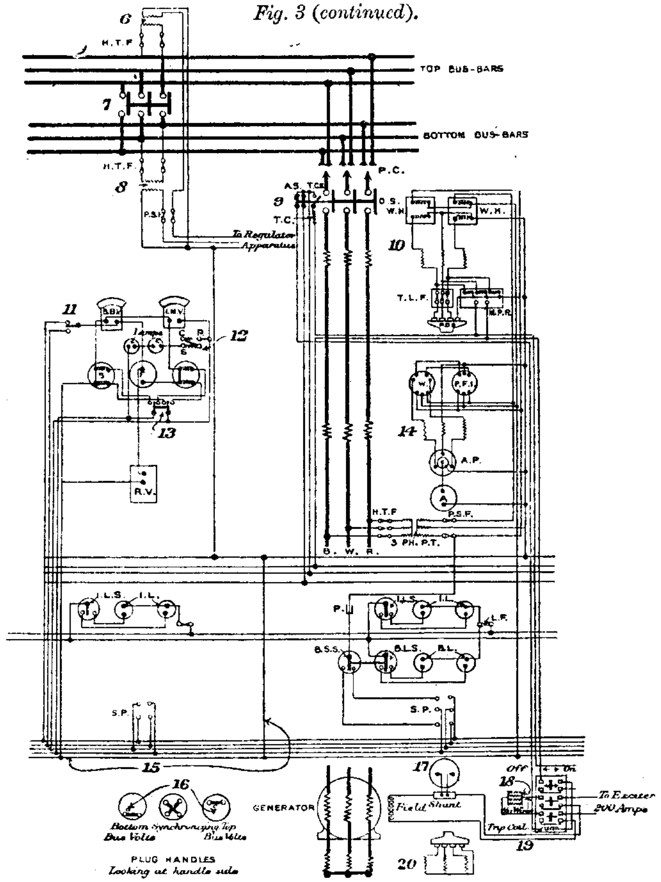


ARRANGEMENT OF SWITCH-

Refer-

(1), (3) Current Transformer for Instruments and Overload Protection.
(2), (4) Current Transformer for Wattmeter.
(5) Duplicate 30-volt supply with Test Ammeter Resistance.
(6) Single-Phase Potential Transformer for Regulator.
(7) Non-automatic Interconnector Switch.
(8) Single-Phase Potential Transformer for Regulator.
(9) Interlocking Switch for Field Connections.
(10) Current Transformer for Generator Protection and Wattmeters.
(11) Switch for Top and Bottom Bus Bar Volts.

Fig. 3 (continued).



GEAR CONNECTIONS.

ences.

(12) 1/1 Potential Transformer for Bright Light Synchronizing.
(13) Switch for changing over Synchroscopes.
(14) Current Transformer for Instruments.
(15) Insulated Earth Wire for Testing Purposes (earthed at one point only).
(16) Dummy Pins to make Plugs Non-Reversible.
(17) Exciter Ammeter.
(18) D.B. Resistance, 4·25-ohm Rods in Parallel.
(19) D.P. Field Switch.
(20) M.P. Generator-Protection Current Transformer.

With the exception of the steam-turbines and alternators, which were ordered in July, 1914, the whole of the contracts were placed during the first 6 months subsequent to the outbreak of the war. As there has since been an average increase of about 60 per cent. in the cost of this class of work, it is obvious that a similar power-station could not now be erected at so low a figure; but comparisons can fairly be made with any power-stations which have been erected since 1914 on contracts placed before the end of that year.

Although the buildings, coal-handling plant and coal-storage yard have been designed and built for a total capacity of 12,000 kilowatts, only 8,000 kilowatts of generating machinery has actually been installed; and to complete the works in accordance with the designs, two boilers, one feed-pump, one 4,000-kilowatt turbo-alternator, and a small amount of additional pipework have yet to be installed. Consequently, in order to arrive at the total cost of the station as designed and the cost per kilowatt, the additional cost of the above-mentioned plant must be allowed for, and this allowance has been made, in the statement set forth below, on the basis of the priced schedules of the various contracts. The additional works could not now be carried out at the schedule prices, but such prices can properly be used in order to ascertain what the actual cost of this 12,000-kilowatt station would have been, had its full complement of plant been contracted for at one time.

The actual costs under the various contracts, and the further capital expenditure, at contract-schedule rates, necessary to provide for the full complement of plant, are shown in Table on p. 215.

Even at pre-war prices, an inclusive cost of about £6 12*s*. per kilowatt is an abnormally low figure, not merely for a power-station of the medium size described, but also for power-stations of four or five times its magnitude: and although at present prices the cost per kilowatt would be increased by, say, 60 per cent., so also would the cost of power-stations with the more usual design of boilers, brick flues, chimneys, and overhead coal-storage.

Compared with the cost of other power-stations for which the Author has been responsible, and also with the published expenditure upon various other power-stations in this country, it would appear that the economy in first cost of the Walsall design is not less than 30 to 40 per cent., and that this saving is due primarily to the type of plant adopted and to the general arrangement and design of the coal-handling plant.

In the foregoing description the Author has endeavoured to show that throughout, the plant, materials, and workmanship are the

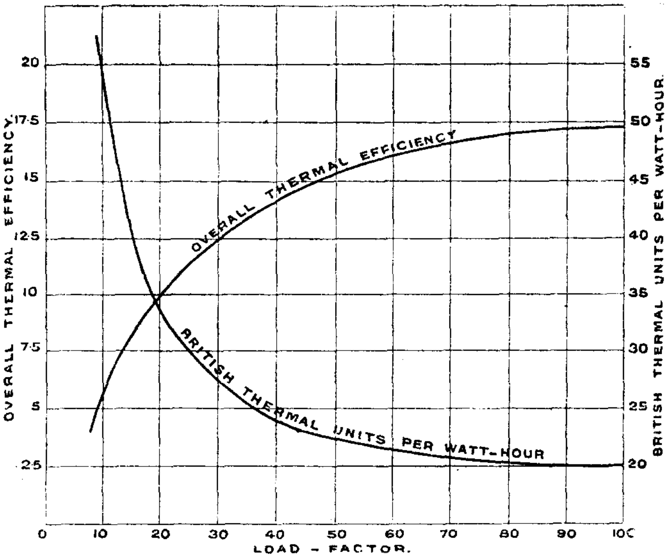
	£	Total Cost. £	Cost per Kilowatt. £
Buildings, coal-storage yard, plant-foundations, canal-water inlet-sumps and outlet-weirs, ash-run, inclined approach-road, fencing, etc.	..	11,625	0·969
Four boiler-units complete with economizers, draught-plant, and chimneys	15,530		
Schedule price for two additional boiler-units	7,770	23,300	1·942
Feed-pumps, feed-water heater, tanks, water-softener, steam exhaust and water-pipes, valves, lagging and painting, etc.	4,452		
Schedule price for one additional feed-pump and additional pipework	925	5,377	0·448
Jib coaling-crane, coal-weigher and main receiving-hopper, coal-conveyer, overhead bunkers, measuring drums, shoots for boilers and coal-stores, ash-trucks and rails, etc.	..	4,450	0·371
Two turbo-alternators and exciters, auxiliary exciter condensing plant, Tirrell regulators, Lea recorders and steam measuring and recording instruments	17,580		
Schedule price for additional 4,000-kilowatt turbine, etc..	8,070	25,650	2·137
Engine-room travelling crane	..	652	0·054
Cabling for two alternators, exciters, auxiliary motors and station-lighting	730		
Cabling for additional alternator and station-motors	200	930	0·077
Two 625-kilovolt-ampere static transformers-ratio 6,600/375 for station-motors	..	540	0·045
Electric high-tension switchgear for the alternators and seven outgoing 1,500-kilowatt feeders and low-tension board for station-motor and lighting	2,540		
Schedule price of electric high-tension gear for third alternator, etc.	400	2,940	0·245
		75,464	6·288
Engineering charges	..	3,773	0·314
Total.	..	79,237	6·602

best of their respective kinds, and that the works are fully equipped with all the essentials and accessories necessary for the operation of an efficient power-station. The object of describing in considerable detail portions of the works which are common to all stations of modern design has been to demonstrate that the whole of the plant and apparatus are of the first order, and that the abnormally low cost can therefore reasonably be attributed to the type and design of certain parts of the works, rather than to the installation of indifferent or inferior plant, or to any sacrifice of efficiency merely for the sake of cheapness.

The main object in the design of this station was to secure the highest practicable concentration of boiler-house plant, with ample space for operation, and also to so arrange the plant as to reduce the labour-charges to a minimum, as it is obvious that economy in first cost only becomes an important factor if it can be shown that, compared with stations of older type, the working-expenses are lower, or at least as low.

The cost of the production of electricity in any coal-burning station is governed principally by the station load-factor, i.e., the ratio of the actual output of the station in kilowatt-hours to the possible output if the station were constantly worked at its maximum load throughout the year. The effect of this load-factor upon the overall thermal efficiency, i.e., upon the ratio of the thermal units in the kilowatt-hours of electricity sent out from the station to the thermal units in the coal fed into the boilers, is shown in *Fig. 4*, and it will be seen that in the case of a general supply with a load-factor of, say, 30 per cent., the overall thermal efficiency is 12·5 per cent., equivalent to 26·5 B.Th.U. per watt-hour sent out.

Fig. 4.



CURVES SHOWING EFFECT OF THE LOAD-FACTOR ON THE OVERALL THERMAL EFFICIENCY.

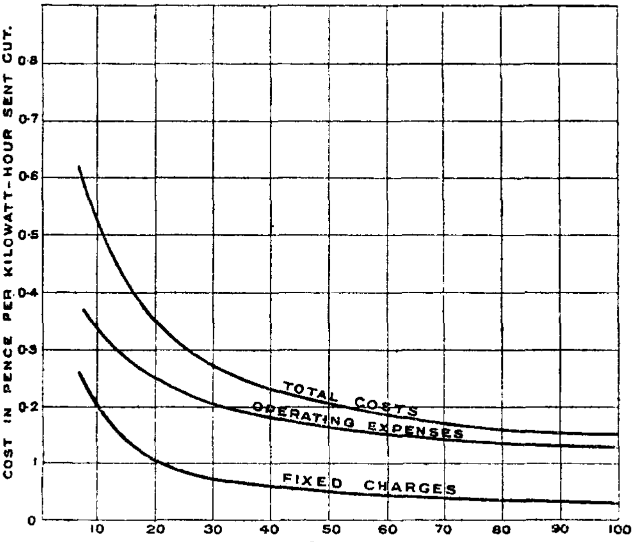
In order to show the total costs of producing electricity, these have been divided as follows:—

Fixed Charges:
- Annual interest on the capital expenditure.
- Sinking-fund necessary to accumulate the cost of plant and buildings at the end of their useful life.
- Insurance.

Working-Expenses:
- Fuel.
- Oil, water, and stores.
- Wages and salaries.
- Repairs.
- Management.

The curves in *Fig. 5* show the total costs, as above defined, at various load-factors, but no allowance is included therein for rates and taxes, as these vary considerably in different localities, and it would serve no useful purpose to adopt a hypothetical amount.

Fig. 5.



Curves showing Effect of Load-Factor upon Total Costs of Production.

The interest on the capital expenditure and sinking-fund is taken at 5 per cent. per annum, and for the life of the plant and buildings an equated period of 25 years is assumed.

Previous to the war, coal of a calorific value of 11,500 B.Th.U per pound could be purchased at Walsall at an average cost of 9*s*. per ton, and it may reasonably be taken that after the war the price should not average more than 12*s*. per ton, which is the amount taken for estimating the fuel-costs. But although fuel is by far the most important item of the working-expenses, an increase of 4*s*. per ton, or 33 per cent., would only increase the total costs by 15 to 20 per cent.

The curves show that for the purpose of a general electricity supply, having a maximum load of 8,000 kilowatts and a load-factor of say 30 per cent., the total cost of production would be approximately 0·275*d*. per kilowatt-hour sent out, exclusive of rent, rates, and taxes. Table III, Appendix II, shows the details of the annual cost of production on the above basis and also includes a provision for rent, rates and taxes. But for a supply such as is required by a frequent service of electrically propelled railway-trains, or for various classes of manufactures with a load-factor of, say, 50 per cent., the total cost of production should not exceed 0·22*d*. per kilowatt-hour, whilst for certain chemical processes requiring almost a constant load, with a resultant load-factor of say 80 per cent., the total costs would approximate to 0·17*d*. per kilowatt-hour.

In addition to the power-station the new works at Walsall include a high-tension system of transmission-mains linking up seven substations, where the pressure is reduced to low-tension direct or alternating current before distribution to the consumers. This portion of the work is only briefly mentioned, as transmission and distribution systems are necessarily designed to meet the particular requirements of a given area of supply and therefore are not of the same general interest as a power-station, which, with but slight modifications would be suitable, not only for the general supply for which it has been designed but also for special supply purposes such as electric railways or other very large users of electricity.

As consulting engineer the Author desires to record his indebtedness to Mr. Bruce Dawson, F.R.I.B.A., with whom he was associated in the design of the buildings and to Mr. H. A. Howie, the present Borough Electrical Engineer, for his assistance during the erection of the works.

The Paper is accompanied by tracings from some of which Plate 3 and the Figures in the text have been prepared, and by the following Appendixes.

[APPENDIXES.

APPENDIXES.

APPENDIX I.

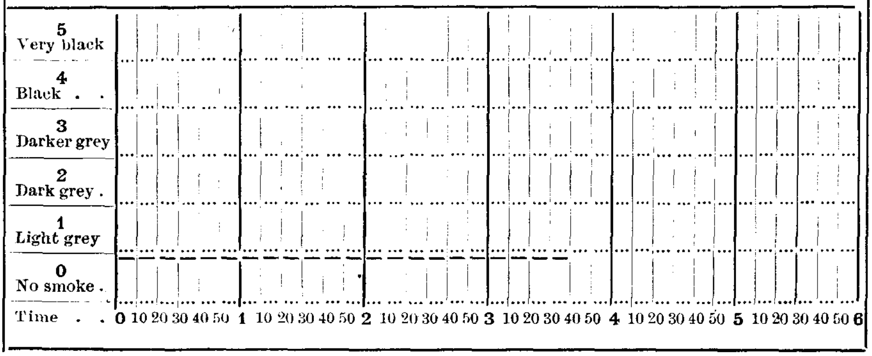
Report on the Trial of a Boiler at the Electricity Works, Amsterdam, Holland.

Made on the 24th March, 1916, under the direction of Messrs. Babcock and Wilcox, in the presence of Dr. Lulofs, Chief Electrical Engineer, and his staff.

Type of boiler, water tube C.T.M.; made by Babcock and Wilcox.
Maker's rating of the output of the boiler, 37,400 lbs. of steam per hour from feed at 90° F.
Test made at an output of 40,359 lbs. of steam per hour.
Object of the trial, to test normal evaporative capacity and efficiency.

Reference Number.	General Description of Boiler and Leading Dimensions.
1	Marine steel-cased boiler, with integral superheater, superimposed economizer and steel chimney. Height, including economizer, 26 feet 3 inches; width over casing, 18 feet; and depth, 14 feet 6 inches.
2	Method of starting and stopping the test: Flying start after boiler had been working several hours and conditions steady. Test finished with fire thickness; draught, etc., the same as at the start.
3	Method of stoking and average thickness of fire: Mechanical chain grate stoker; fire thickness 4½ inches.
4	Production of draught: Cold air ejector.
5	Chimney height: 94 feet.
6	Total grate surface (excluding dead plate): 210 square feet.
7	Grate area occupied by air space between bars: Not measured.
8	Total heating surface: 4,963 square feet.
9	Capacity of water space at — inches in gauge glass: — cubic feet.
10	,, steam ,, ,, — ,, ,, — ,,
11	Area of water surface in boiler ,, — ,, ,, — ,,

Smoke Diagram.



BOILER. Sheet II.

DATA DEDUCED FROM OBSERVATIONS.

Reference Number.	Particulars of Observations.	Abstract of Observations.
12	Duration of Trial, from 11·49 to 3·35 hours	3 hrs. 46 mins.
	FUEL.	
13	Short description	Washed nuts.
14	Fired per hour . . . lbs.	4,489
15	Analysis by weight of fuel—	
	Carbon . . . per cent.	75·04
	Hydrogen . . . ,, ,,	4·31
	Sulphur . . . ,, ,,	0·90
	Ash . . . ,, ,,	5·12
	Nitrogen, oxygen and other matters ,, ,,	10·62
16	Moisture in fuel as fired . . . ,, ,,	4·01
17	Calorific value of fuel as fired (“lower” value) B.Th.U. per lb.	12,816
	ASH AND CLINKER.	
18	Total per hour . . . lbs.	Not measured.
19	Carbonaceous matter in ash per hour . . . ,,	,, ,,
20	Calorific value of ash . . . per lb.	,, ,,
	FLUE GASES.	
21	Analysis of dry flue gases—	By Volume. By Weight.
	Carbonic Acid . . . per cent.	12·7 18·54
	Carbonic Oxide . . . ,, ,,	Nil. Nil.
	Oxygen . . . ,, ,,	6·3 6·65
	Nitrogen (by difference) . . . ,, ,,	81·0 74·81
22	Average temperature leaving boiler flues . . . °F.	580
23	Mean specific heat of products of combustion . B.Th.U.	0·254
	AIR AND DRAUGHT.	
24	Temperature of outside air . . . °F.	60
25	Barometric pressure (inches Mercury) lbs. per sq. in.	Not measured.
26	Pressure in ash pit (forced draught) . . inches of water	Open ash pit.
27	Suction over fire . . . ,, ,, ,,	0·25
28	Draught at gas exit from boiler . . . ,, ,, ,,	Not measured.
29	,, base of chimney . . . ,, ,, ,,	0·95
30	Weight of steam per hour used in producing draught lbs.	448
	FEED WATER.	
31	From pump, economizer or feed heater per hour . . lbs.	40,359
32	Temperature of feed to boiler . . . °F.	255
	STEAM.	
33	Gauge pressure . . . lbs. per sq. inch	149
34	Absolute pressure . . . ,, ,, ,, ,,	164 approx.
35	Total moisture in steam . . . per cent.	Not measured.
36	Temperature of saturation . . . °F.	365

BOILER. Sheet III. HEAT ACCOUNT AND DEDUCTIONS.

Reference Number.	HEAT ACCOUNT (per lb. of fuel as fired).	B.Th.U.	Per Cent.
37	Total heat value of 1 lb. of fuel as fired	12,816	100·0
38	Heat transferred to the water (*thermal efficiency*)	10,242	79·92
39	Heat carried away by products of combustion	1,459	11·38
40	Heat carried away by excess air	532	4·15
41	Heat lost by incomplete combustion	Nil	..
42	Heat lost by unburnt carbon in ash	Not measured	..
42a	Heat in red-hot clinker and ash	,,	..
43	Loss per hour by radiation	,,	..
44	Balance of heat account. Errors of observation, and unmeasured losses, such as those due to radiation, escape of unburnt hydrocarbons, loss in hot ashes, etc.	583	4·55
	Total of lines 38 to 44, equal to line 37	12,816	100·0
	DEDUCTIONS.		
45	Heat transmitted per square foot of heating surface per hour B.Th.U.		7,903
46	Weight of fuel fired per square foot of grate per hour lbs.		21·38
47	Water evaporated per lb. of fuel as fired lbs.		8·99
48	Equivalent evaporation from and at 212° F. per lb. of fuel as fired lbs.		10·54 including superheater
49	Weight of feed from and at 212° F. per square foot of heating surface per hour lbs.		9·53 including superheater effect
50	Velocity of steam across water surface feet per second		Not measured
51	Air used per lb. of fuel as fired lbs.		14·31
52	Air theoretically required per lb. fuel as fired lbs.		10·10
52a	Excess air used lbs.		4·21
53	Ratio of air used to air theoretically needed		1·41
54	Weight of products of combustion per lb. of fuel as fired lbs.		11·05
55	Weight of gases per lb. of fuel as fired lbs.		15·26
56	Heat carried away by gases per lb. of coal as fired B.Th.U.		1,991

ECONOMIZER AND SUPERHEATER. Sheet I.

GENERAL DESCRIPTION AND DIMENSIONS.

Reference Number.	ECONOMIZER.
57	General description of Economizer, and arrangement of flues, etc. Horizontal steel tube three pass, on top of boiler.
58	Heating surface of economizer, 4,086 square feet.
	SUPERHEATER.
59	General description of Superheater and method of heating it. Integral.
60	Heating surface, 1,813 square feet.

DATA DEDUCED FROM OBSERVATIONS.

Reference Number.	ECONOMIZER. (Heating of feed by flue gases.)	Abstract of Observations.	
61	Weight of feed water entering economizer per hour . . . . lbs.	40,359	
62	Temperature of feed into economizer . . ° F.	135	
63	,, ,, out of ,, . . ,,	255	
64	,, flue gases into economizer . ,,	580	
65	,, ,, out of ,, . ,,	293	
	Analysis of dry flue gases leaving economizer—	By Volume.	By Weight.
66	Carbonic acid. . . . . per cent.	12·5	18·25
	Carbonic oxide . . . . ,,	Nil.	Nil.
	Oxygen . . . . ,,	6·5	6·86
	Nitrogen (by difference). . . . ,,	81·0	74·89
67	Mean specific heat of flue gases leaving economizer B.Th.U.	0·248	
	SUPERHEATER.		
68	Weight of steam entering superheater per hour lbs.	40,359	
69	Steam pressure (absolute) into superheater lbs. per square inch	164 approx.	
70	Moisture of steam into superheater . . per cent.	Not measured.	
71	Temperature of steam into superheater . . ° F.	365	
72	,, ,, out of ,, . . ,,	675	
73	,, of flue gases into ,, . . ,,	Not measured.	
74	,, ,, out of ,, . . ,,	,,	,,
	Analysis of dry flue gases leaving superheater—	By Volume.	By Weight.
75	Carbonic acid. . . . . per cent.	Not measured.	
	Carbonic oxide . . . . ,,	,,	,,
	Oxygen . . . . ,,	,,	,,
	Nitrogen (by difference). . . . ,,	,,	,,
76	Mean specific heat of flue gases leaving superheater B.Th.U.	,,	,,

ECONOMIZER AND SUPERHEATER. Sheet II.

HEAT ACCOUNT AND DEDUCTIONS.

Reference Number.	HEAT ACCOUNT (per lb. of fuel as fired).	B.Th.U.	Per Cent.
	ECONOMIZER.		
77	Heat received from boiler flues, in gases and steam, per lb. of fuel as fired (reckoned from air temperature)	1,991	100·0
78	Heat transferred to the water (*efficiency of economizer*)	1,079	54·19
79	Heat carried off in the chimney gases . .	897	45·05
80	Balance of Heat Account, including errors of observation, and difference of heat contained in brickwork at beginning and end of tests, etc.	15	0·76
	Total of lines 78 to 80, equal to line 77 .	1,991	100·0
	SUPERHEATER.		
81	Heat received from flue gases and steam, per lb. of fuel as fired (reckoned from air temperature)	..	100·0
82	Heat transferred to steam (*efficiency of superheater*)	Included in Boiler	
83	Heat carried off in the chimney gases . .	,,	,,
84	Balance of Heat Account, including errors of observation, etc.	,,	,,
	Total lines 82 to 84, equal to line 81 .	..	100·0
	DEDUCTIONS.		
85	Heat transmitted per square foot of heating surface of economizer per hour . . .	B.Th.U.	1,185
86	Heat transmitted per square foot of heating surface of superheater per hour . . .	B.Th.U.	3,726
87	*Thermal efficiency* of boiler, superheater and economizer combined	per cent.	88·33

APPENDIX II.

TABLE I.

Steam-consumption per kilowatt-hour, of Belliss–Siemens turbo-alternators, with a steam-pressure of 180 lbs. per square inch at the stop-valve, 600° F. steam-temperature, and a cooling-water temperature of 75° F.

Load in Kilowatts.	Pounds of Steam per Kilowatt-Hour.	Vacuum in Inches.
4,500	13·38	27·5
3,750	12·40	28·0
3,000	12·58	28·15
2,250	13·15	28·35
1,500	14·45	28·5

TABLE II.—See p. 225.

TABLE III.—ESTIMATE SHOWING THE ANNUAL COST AND COST PER KILOWATT-HOUR ON A STATION LOAD-FACTOR OF 30 PER CENT.

Capital expenditure	£79,237
Life of plant	25 years.
Capacity of plant	12,000 kilowatts.
Maximum load	8,000 ,,
Load-factor	30 per cent.
Kilowatt-hours per annum	21,024,000.

	Cost per Annum. £	Cost per Kilowatt-Hour. *d.*
Operating expenses :—		
Fuel, 22,800 tons at 12*s.*	13,680	0·156
Oil, water, waste, etc.	260	0·003
Wages	1,560	0·018
Repairs and maintenance	2,100	0·024
Management	700	0·008
Rent, rates, and taxes	1,314	0·015
	19,614	0·224
Fixed charges :—		
Interest and Sinking-Fund on 5 per cent. tables, £79,237 × 0·07095	5,622	0·064
Insurance	174	0·002
Total cost per annum and per unit	25,410	0·290

TABLE II.—LOSSES AND EFFICIENCIES FROM LIGHT-LOAD TESTS OF SIEMENS ALTERNATORS.

Power Factor.	Cos $\phi = 0\cdot8$.					Cos $\phi = 1\cdot0$.				
Load . . . . Kilowatts	4,500	3,750	3,000	2,250	1,500	4,500	3,750	3,000	2,250	1,500
Stator current loss C^2r + 20 per cent.	32·5	22·5	14·4	8·1	3·6	20·8	14·4	9·2	5·2	2·3
Rotor current amperes . .	215	192	167	146	125	139	126	114	103	95
Rotor and regulator loss Kilowatts	26·8	24	20·9	18·2	15·6	17·4	15·7	14·2	12·9	11·9
Iron, friction and windage loss . . . . Kilowatts	192	192	192	192	192	192	192	192	192	192
Total loss . . . Kilowatts	251·3	238·5	227·3	218·3	211·2	230·2	222·1	215·4	210·1	206·2
Output . . . Kilowatts	4,500	3,750	3,000	2,250	1,500	4,500	3,750	3,000	2,250	1,500
Input . . . . Kilowatts	4,751	3,988	3.227	2.468	1,711	4,730	3,972	3,215	2,460	1,706
Efficiency per cent. . . .	94·7	94	93	91·2	87·7	95·1	94·3	93·3	91·5	87·9

BIRCHILLS ELECTRIC POWER-HOUSE,

WALSALL

PLATE 3.
BIRCHILLS ELECTRIC POWER-HOUSE

Figs. 1.

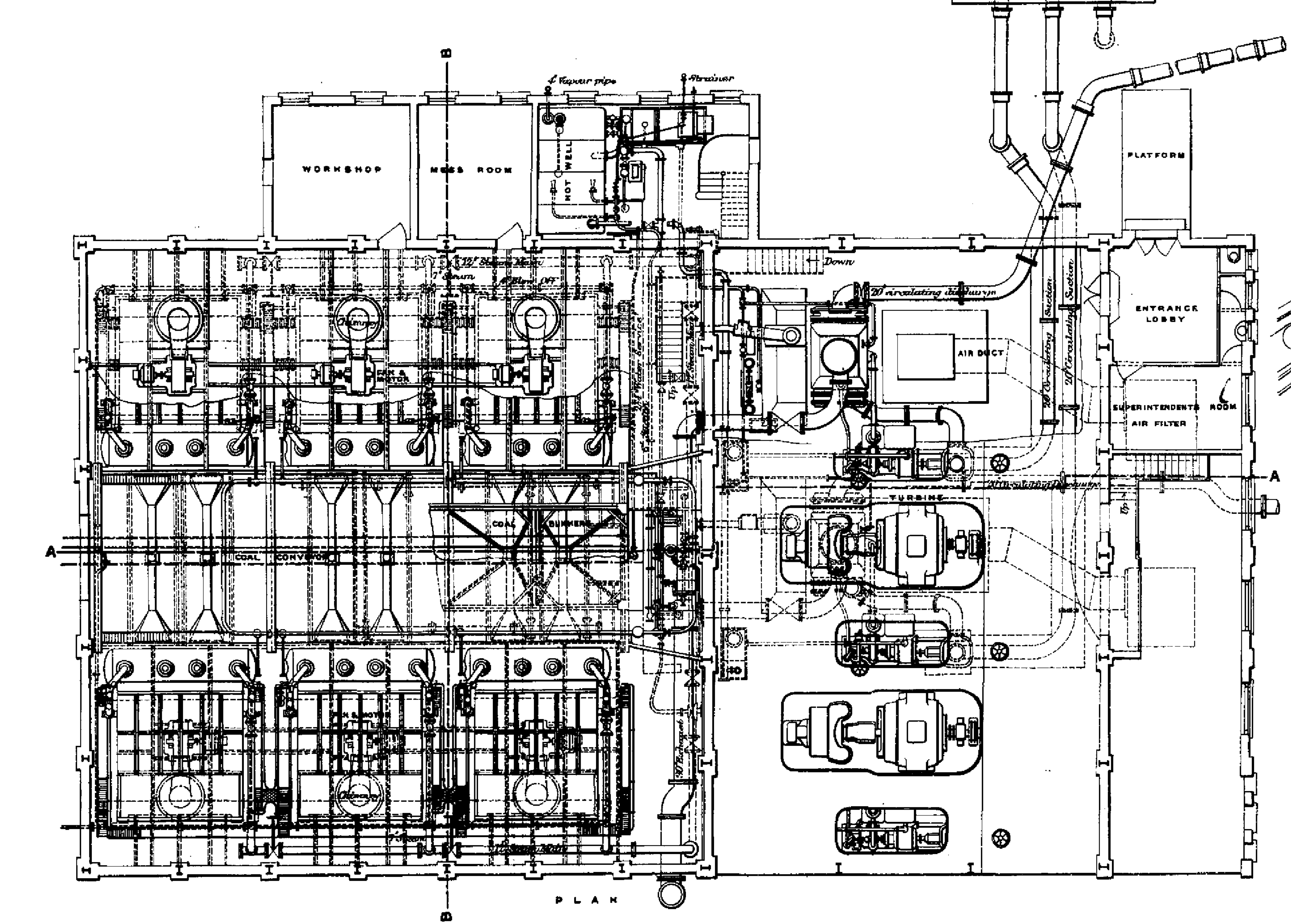
— SCALES —

Figs. 1……1 Inch – 16 Feet

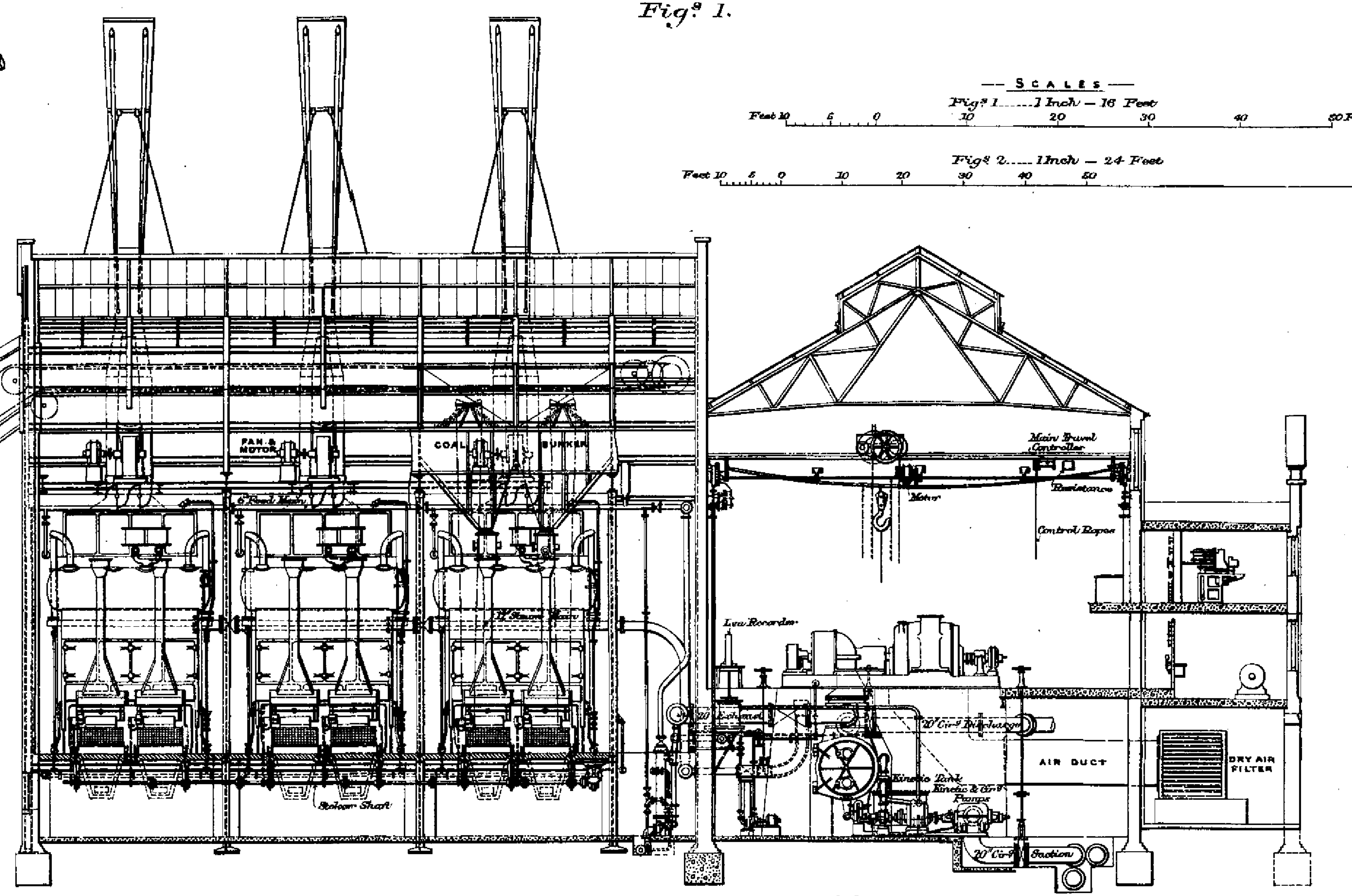
Feet 10 5 0 10 20 30 40 50 Feet

Figs. 2……1 Inch – 24 Feet

Feet 10 5 0 10 20 30 40 50 100 Feet

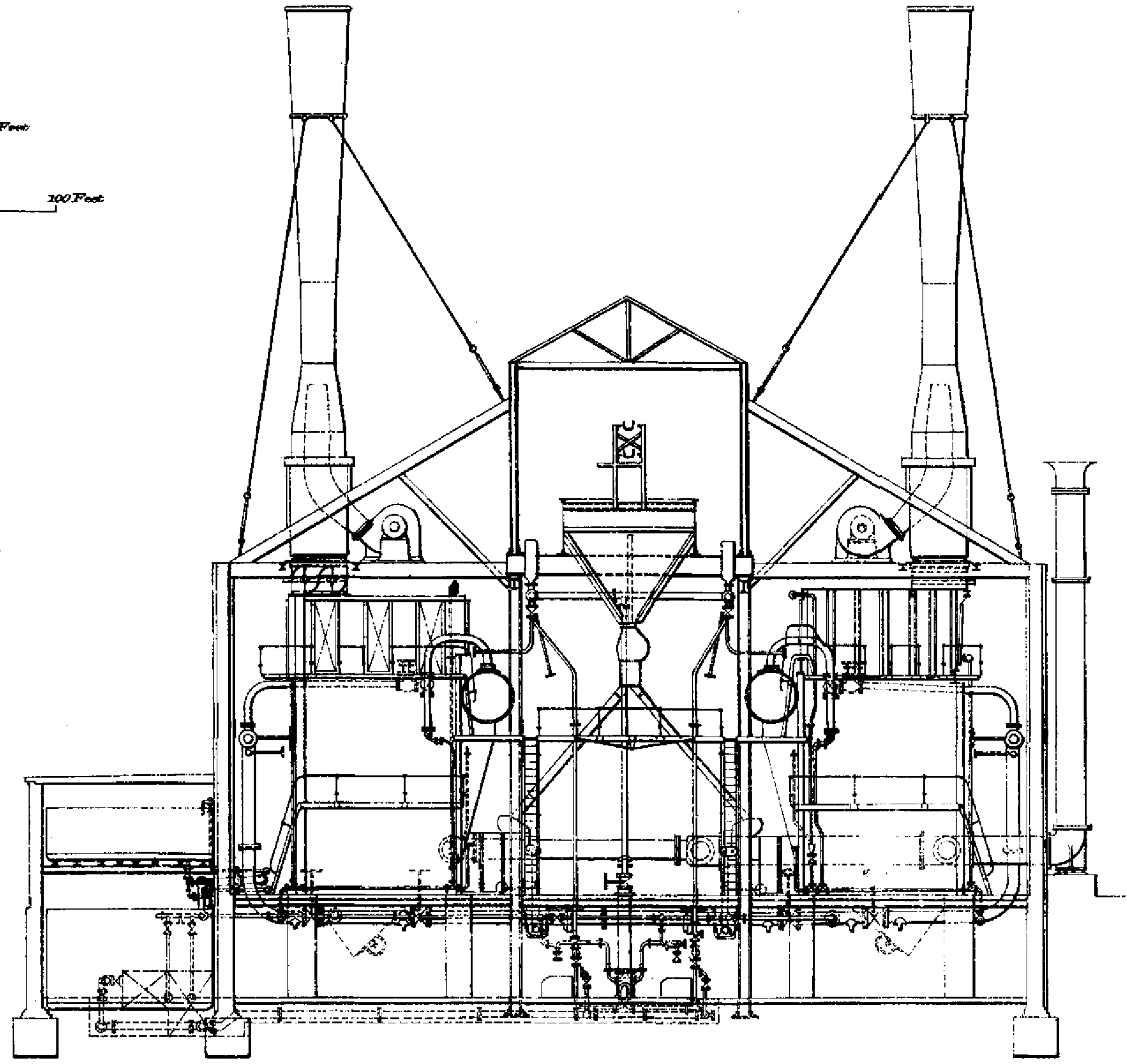


PLAN



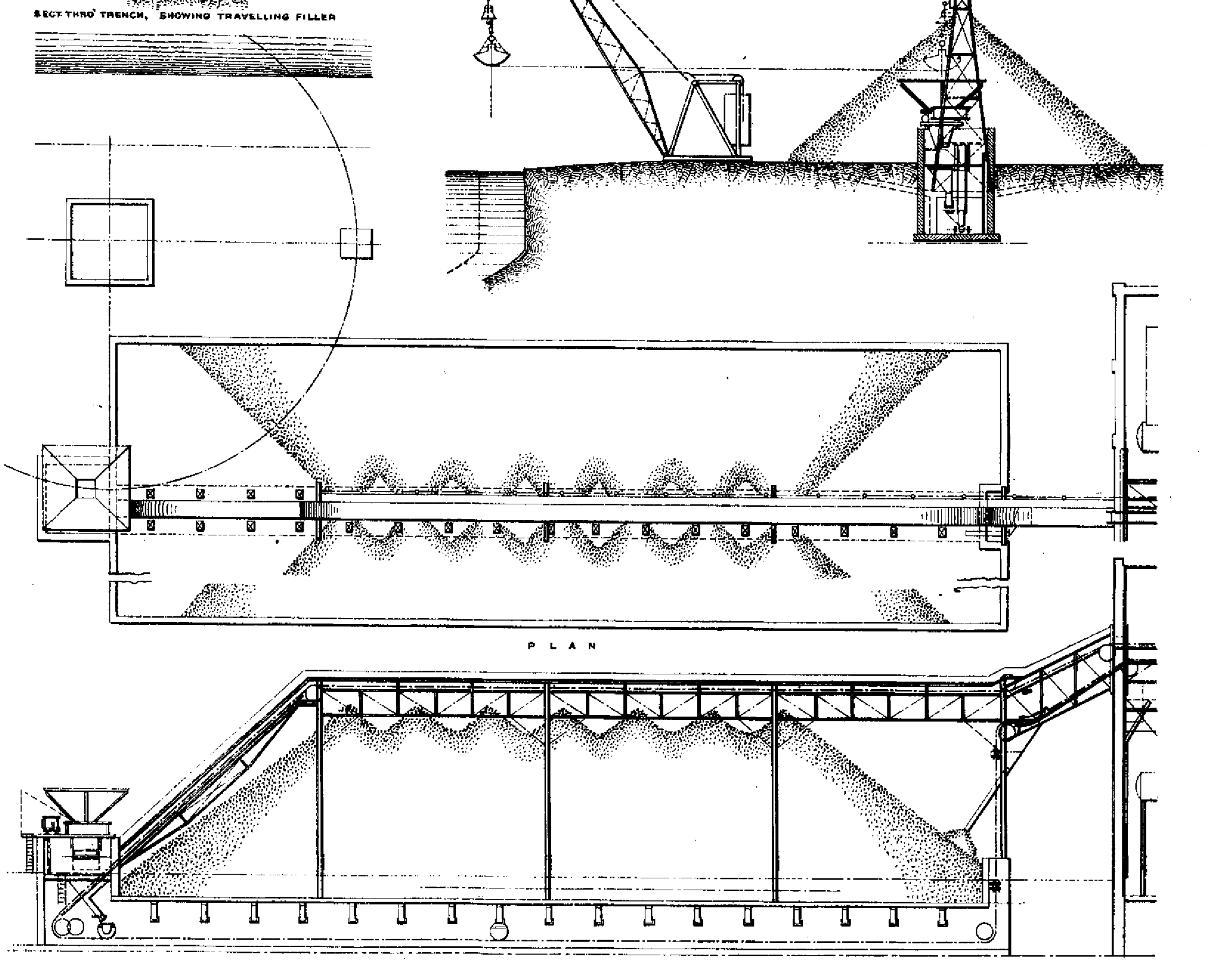
LONGITUDINAL SECTION ON AA

GENERAL ARRANGEMENT OF POWER-HOUSE



CROSS SECTION THROUGH BOILER-HOUSE (BB)

Figs. 2.



ELEVATION

GENERAL ARRANGEMENT OF COAL-HANDLING PLANT

E. M. LACEY.

WATERLOW BROS. & LAYTON LTD. LAKE MELLS, LONDON.

Minutes of Proceedings of The Institution of Civil Engineers. Vol. CCIV Session 1916-17 Part II.