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The Canadian Society of Civil Engineers.

INCORPORATED 1887.

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STEAM TURBINE POWER AND TRANSMISSION PLANT OF THE MOCTEZUMA COPPER COMPANY, AT NACOZARI, SONORA, MEXICO.

By JOHN LANGTON, M. Can. Soc. C. E., and CHARLES LEGRAND

(To be read before the Electrical Section, March 5, 1908.)

This power plant was erected to provide for a large extension in the operations of The Moctezuma Copper Company, both at its works, situated at Nacozari, and at its mines, six miles distant. The plant was planned with the aim of providing comprehensively, not merely for present needs, but for all probable contingencies, and for possible further extensions.

The duty on crude petroleum into Mexico being prohibitive, and the wood supply in the neighborhood being inadequate to furnish fuel for a steam plant of the requisite capacity, coal is the only available fuel; and bituminous coal from northern New Mexico is the nearest and cheapest to be had. Since this coal has to be hauled 750 miles by rail to Nacozari, its excessive cost required that the plant should be planned for the greatest fuel economy consistent with that simplicity in operation which is essential in a plant which must run continuously in an isolated situation, such as Nacozari, where skilled labor is frequently scarce. The cost of fuel dictated the addition of economizers to the boilers, and also superheaters to give a moderate degree of superheat.

After careful investigation, and consideration of all the conditions, both local and general, it was decided to use steam turbines.

The water at Nacozari is saturated with lime salts, and deposits hard scale in large quantities in the boilers, unless it is chemically treated to replace the lime salts by sodium sulphate. In the latter case great waste is involved in blowing off the boilers to keep down the degree of concentration of the sodium sulphate in solution, which would otherwise cause foaming. The use of steam turbines, and the consequent absence of oil in the exhaust steam, makes it easily possible to get pure feed water for the boilers by using surface condensers, thus transferring scale deposit from the economizer and boiler tubes to those of the condenser, where it is more easily dealt with, and where, at the lower temperature, the deposit will possibly be lessened.

In addition to the water being hard, it is also scarce in the dry season, and very turbid and full of sediment during the rains. Of necessity, in times of scarcity, and for the sake of clear water in times of plenty, the condensing water is passed over a cooling tower, the new water supplied being only that quantity needed to make up for the evaporation in the cooling tower. Whether it will be cheaper to treat this water supply chemically, or to expend labor in scaling the condenser tubes, remains to be determined by experience.

The near-by load on the power plant is about 1000 K. W. This is consumed by the concentrating mill, the town lighting, and a few general service motors, and is approximately fixed in amount. The transmission load is about 500 K. W., and this is the portion of the load which is most likely to require extension, possibly in several directions; since the broken and mountainous character of the country, the scarcity of cheap fuel, and of water of any kind, make any but transmitted power for mining operations very costly. It was therefore decided to generate power at a voltage suitable for direct transmission to the mine, having in mind also that step-down transformers would, in any case, be needed for the bulk of the near-by load, since no good site for the power plant could be found sufficiently near the concentrating mill to permit transmission of the mill power at motor-voltage.

Description of Power Plant.

The plan and sectional elevation of the plant are shown by Fig. 1 and Fig. 2. The framework of the buildings is steel. The roofs are corrugated steel. The walls of the boiler room are also corrugated steel. The outside wall of the turbine room is concrete, and the partition between the turbine room and the boiler room is reinforced concrete.

The coal has to be hauled through that section of the semi-arid western country where railroad traffic is subject to severe interruptions when it rains, either due to track washouts caused by cloudbursts, or to the loss of bridges torn away by the debris carried along by floods in the usually dry beds of streams. To insure continuous operation of the plant it is therefore necessary to carry a large stock of coal at all times. It was considered desirable to provide storage for one month's fuel consumption. Storage by reserve stock pile entails the expense of double handling, and with bituminous coal involves deterioration, both in heat value and in physical character. Some form of bin storage, by which the whole stock is carried in the bins, and is continually moving through them, is therefore very desirable.

The form of storage adopted for this plant is that shown by the coal dock, numbered 18 in Fig. 1 and Fig. 2. The site selected afforded the opportunity of getting a trestle for main line cars thirty-three feet above the boiler room floor, at the cost of a spur of moderate length from the main line, and a short trestle approach, both on a four per cent. grade. The trestle continues over the coal dock on a level, and twenty-four feet above the floor of the dock. This floor is of reinforced concrete, resting on a series of transverse walls. The two ends and one side of the dock have reinforced concrete walls twelve feet high. For the present the wall on the side next the boiler house is omitted, though anchorages are provided by which it may be added in the future if desired.

The transverse foundation walls form a series of tunnels under the dock, in each of which coal may be drawn from the bottom of the pile through the hoppers and coal valves shown, fresh coal being unloaded on top of the pile direct from the main line cars. The dock constructed holds 1200 tons. An extension to double this capacity is shown on the plan in dotted lines.

With the fuel consumption in immediate prospect, and with the labor conditions which obtain at Nacozari, it was considered that hand firing would at present be most economical. The coal is brought to the boilers in charge cars holding one ton of coal each, and ashes loaded by hand into small dump cars which are then pushed to a point where they are discharged into main line cars on a spur from the main line, the latter being parallel to the boiler house, 150 feet distant from it, and twenty-six feet below the level of the boiler room floor.

All charge car and ash car tracks are on the boiler room floor level, and are without grade.

In case future extension and other developments make it profitable to use automatic stokers, provision is made for delivering coal to them from the coal storage dock, by means of the apparatus indicated by broken lines in Fig. 2. Coal, fed by gravity from the present hoppers to a spiral conveyor for which openings (shown in Fig. 2) are provided in the transverse walls, will be carried by the conveyor to the central transverse passage between the two coal docks. This passage will be excavated to a depth of about twelve feet below the boiler room floor, giving space for crushing rolls, and drop enough to feed the lump coal by gravity through the rolls to the boot of an elevator. This elevator will either deliver the crushed coal to a pocket running the length of the boiler house, suspended from the roof truss; or, if it is preferred to deliver coal to the stokers by charge cars, the elevator will deliver to a small crushed coal bin. In the first case, spiral conveyors will distribute the coal along the length of the pocket, from which it will be drawn through weighing chutes to the hoppers of the automatic stokers. In the second case, charge cars filled from the crushed coal bin and weighed, will run on a platform placed at a convenient height for the cars to discharge into the hoppers of the stokers.

If desirable and profitable in the future, the excavated central transverse passage may be continued into the boiler room, and carried along the front of the boilers, under the boiler room floor, forming a basement about 12 feet high, which will allow the use of hopper-bottomed ash pits, discharging their contents either into cars, or to a suitable ash conveyor.

Stirling boilers, Class A, are used; 435 H. P. each, with safety valves set to pop at 160 pounds gauge pressure. Each boiler is equipped with a Foster superheater, to give 75° Fah. superheat. Directly back of, and in continuation of, each boiler is a 160-tube Greene fuel economizer, 16 rows of 10 tubes wide. The gases from the economizer, or from the bye-pass flue beneath the economizer, pass into the main flue, 8 feet wide by 9 feet high, and thence to the central stack, 12 feet inside diameter and 184 feet in height above the boiler room floor. In addition to dampers at each economizer, and at each bye-pass flue, main flue dampers are provided, one at each side of the stack, to be operated by automatic damper regulators. The boilers and economizers are set in brickwork, but all flues are of concrete, with reinforced concrete roof. The stack is entirely reinforced concrete construction.

The boiler feed pumps are placed in the central space opposite the stack. They draw from two small tanks adjacent to them, and placed to give a suction head to the pumps. Condensed water, live steam drips, and any fresh water needed to make up feed, are delivered to these suction tanks. There are two geared triplex pumps, driven by variable speed induction motors, one in operation and one in reserve; and a duplex steam pump for emergencies. The latter is also piped to give high pressure cold water to the turbine scale borers, for scaling boiler and condenser tubes.

The main steam pipe is eight inches in diameter, and is a ring system, divided into sections by gate valves to allow repairs to piping or branch valves without a general shut down. All piping is overhead.

The turbine room contains three 1000 K. W. Curtis turbo-generators. They run at 1800 revolutions per minute, and are 3-phase, 60 cycle 6600-volt machines. One turbine is always in reserve. Each turbine has its own condenser, air pump, and circulating pump.

The condensers are counter-current Alberger surface condensers, with a motor-driven dry vacuum pump. By carrying the condensed water drain pipes a short distance outside the building to a seal tank, a sufficient difference of elevation is obtained to give a barometric column. This obviates the necessity of a condensed water pump at each condenser. Two simple low-lift centrifugal pumps, motor-driven, are provided at the seal tank to return the condensed water to the feed pump suction tanks in the boiler room. One centrifugal pump is in operation and one always in reserve.

The circulating pumps are of the Root or Connersville impeller type. They are motor-driven, and handle 3000 gallons per minute each.

The cooling tower is placed on a tableland, which begins about one hundred feet back of the power plant, and which is fifty-five feet higher than the boiler room floor level. It is of the open atmospheric type, which is found very satisfactory in the dry, western climate, where, for the greater portion of the year, the relative humidity is about thirty per cent.

A 24-inch cast iron pipe, 150 feet long, carries the circulating water from the cooling tower sump to the turbine room, along which it runs with a branch to each condenser. The valves in these branches are the only ones in the circulating water system. The elevation of the cooling tower sump gives a static head of 35 feet at the condensers; the circulating pumps draw from the condensers, and each pump delivers through its own 16-inch pipe, opened at the top of the cooling tower, 14 feet above the level of the water in the cooling tower sump.

The turbines and condensers are set high enough above the floor to give head room under the pipes, draining water from the condenser, and oil from the footstep bearings of the vertical turbines. This sets the operating gallery for the turbines at 12 feet above the floor. In the middle section of the turbine room this gallery is continued to the back wall of the room, and carries the main switchboard and a 50 K. W. motor-driven exciter, with space for a second identical exciter. A feeder from the main high tension switchboard supplies three 75 K. W. station transformers placed under the gallery, which furnish 230-volt current to an adjacent distributing switchboard, whence wires, run on the underside of the gallery floor, supply all the motor-driven station apparatus and auxiliaries.

The circulating pumps and air pumps are on the main floor, as are also the oil filter and the two steam-driven oil pumps which supply the turbines, and a steam turbine-driven 50 K. W. exciter; space is provided for a second steam-driven exciter.

The overhead crane will reach all machines, and carry them to or from a truck or car which may be run into the building in the vacant floor space left for that purpose. The station transformers under the gallary are alone out of reach of the crane, and they therefore stand on small trucks, that they may be wheeled out into a space accessible to the crane.

The pole line wires pass out from the lean-to behind the switchboard, which contains the arrangement of wires for connecting any pole line wire to any feeder panel, and also the lightning arrester and choke coil system.

Normally, the plant is run with motor-driven auxiliaries throughout, but in starting up, or in case of accident to the station feeder or the transformers, the steam-driven boiler feed pump and the steam-driven exciter, enable the plant to operate with the turbine on open-air exhaust, each turbine having its own atmospheric relief valve and open-air exhaust pipe.

The turbine room exemplifies the concentration of power which is possible with steam turbines; the three 1000 K.W. machines with condenser and auxiliaries, and with switchboards and exciters, being comfortably housed in a floor space 45 feet by 72 feet; practically one kilowatt per square foot.

The four boilers at present installed are for the immediate load of 1500 K.W.; three boilers under steam and the fourth a spare, for cleaning and repairs. One or two more boilers, depending on what the load factor and the peak loads of the increased consumption may prove to be, will be needed to bring the boiler plant up to the full capacity of two turbines. An extension for two or more boilers is shown by dotted lines in Fig. 1.

Electrical Distribution.

As stated previously, the load consists of a few scattered motors, the town lighting, the concentrator, and the mine motors and lights.

The feeders are all of bare half hard-drawn copper wires, spaced 24" apart, except between the transmission line and the mine.

Where transformers are operated in parallel, or are likely to be operated in parallel in the near future, they are provided with a primary oil switch and a secondary knife switch. These switches are located near each other so that a simple mechanical interlocking arrangement is used to prevent secondary switch being left closed when primary switch is open. This locking device permits the opening of secondary switch with primary switch closed, but secondary switch cannot be closed if primary switch is open, or primary switch opened without first opening secondary switch. This device is used to prevent a man working on transformer from forgetting to open secondary switch.

Concentrator.

The house which contains the transformers for furnishing current to the concentrator motors and lights, is a two-storey fireproof building, 20' x 32', with concrete walls, steel trusses and corrugated iron roof. The floor, made to stand a load of 1000 pounds per square foot, is the so-called multiplex plate (a corrugated steel plate with a special form of corrugation) filled with concrete. The building is provided with two 48" adjustable ventilators and the necessary openings in the floor and lower walls to insure a good circulation of fresh air in both storeys.

The ten 125 K.W. transformers are located in the upper storey, and are connected in groups of three on each phase; the tenth transformer is a spare one, which can be connected to any of the three phases.

The high tension wires, after passing through choking coils are run on insulators on the bottom chord of roof trusses. Low equivalent lightning arresters are connected to each wire where it enters the building.

The primary of each transformer is connected to its proper phase through an automatic two-pole oil switch and two single pole disconnecting switches. The secondary of each transformer is connected to the distributing switchboard bus bars through a two-pole knife switch with enclosed fuses. The primary and secondary switches are interlocked as explained above.

The secondary wiring between transformers and switchboard bus bars is arranged to give as nearly as possible an equal load on each transformer connected to the same phase.

The distributing switchboard is located in the lower storey, where there are no high tension wires, and consists of eight panels of black enamelled slate, on which are mounted sixteen 3-pole feeder switches with fuses.

Three transformers in parallel were used on each phase, instead of a single one, for several reasons:

1st.—The transformers had to be self-cooling to reduce attention to a minimum.

2nd.—In case of trouble with one transformer, the operation of the concentrator would hardly be interfered with.

3rd.—Greater ease of handling.

4th.—Figuring on having a spare unit, which is necessary when plant is so far from manufacturers and continuous operation is of the utmost importance, the total cost is smaller.

These advantages more than balance the slightly decreased efficiency and difficulty of maintaining an equal load on transformers connected in parallel.

The transformer house is situated as nearly as possible at the centre of the load and over half of the load is within a 300′ radius.

The motors connected to these transformers consist of four 150 H. P., one 75 H. P., five 50 H. P., one 30 H. P., eight 20 H. P., five 10 H. P., and nine 5 H. P., also the equivalent of about a thousand 16 C. P. lamps. Two 50 H. P. and the 75 H. P. and 30 H. P. motors are to run for 10 hours a day, the other motors run continuously.

Inside of the building, where it would not necessitate too large a cable, three conductor cables were used instead of three single wires.

The secondary distribution was made at 220 volts instead of 440 volts to permit the use of incandescent lamps on the same feeders as the motors, and also to reduce the trouble with insulation, a concentrating mill for copper ore being a very wet building.

MINE.

The power is transmitted to the mine at Pilares, 5½ miles from Nacozari, by a line consisting of 3 No. 2 wires spaced 32″ apart, mounted on porcelain insulators suitable for 20,000 volts. The poles are of Michigan cedar with 6″ tops, spaced at an average distance of 130 feet.

The transmission line has been operated at 6600 volts and 25 cycles from another power plant, and in three years' operation has not given any trouble from lightning or other causes, although a great many insulators are broken by being used as targets for revolver shooting.

At Rosario, 3½ miles from Nacozari, are located three 10 K.W. transformers with necessary switches and lightning arresters. They are used to operate a motor-driven pump delivering water against 600′ head, to a tank at Porvenir. A part of this water is used for steam locomotives operating on the railroad between the mine and the concentrator; the rest is pumped 700′ higher to Pilares for domestic use.

At a point 5 miles from Nacozari, the line divides in two branches, one going to the Pilares shaft, the other to the Y shaft. At Pilares are located three 15 K.W. transformers for lighting and power circuits on the surface and in the mine. At the Y shaft are located two 300 K.W. 6-phase 260-volt rotary converters, one 150 H. P. 220-volt induction motor driving a compound air compressor and three 15 K.W. transformers for lighting and power circuits on the surface and in the mine; these transformers operate in parallel with those at Pilares, their circuits being connected through the mine workings, and both sets are provided with primary and secondary interlocking switches.

The air compressor is belt-driven, and delivers air at 100 lbs. pressure for the operation of air drills in the mine.

The direct current from the rotary converters is used to operate electric locomotives in the mine and on the surface, two electric hoists, one at the Y shaft, the other at Pilares shaft, and one stationary motor at Porvenir driving pump mentioned previously.

The electric locomotives in the mine consist of three 10-ton locomotives for 36″ gauge, of which any two are operated in tandem from one controller by means of cable connections; they are equipped with air brakes. This tandem arrangement was used in preference to a 20-ton locomotive, because when the use of a 20-ton locomotive became necessary, a 10-ton locomotive was already in service. It was also difficult to get a 20-ton locomotive for the narrow gauge and with the necessary clearances to operate in mine tunnel. It also gave a spare half unit corresponding practically to a whole spare unit.

The trolley pole is of the "scissors" type, with a roller two feet long instead of a wheel, capable of 8 feet vertical motion as the locomotives have to operate outside of the mine in the same yard with the steam locomotives. This trolley pole has no lateral motion. The trolley wire in the mine is 8 feet from the rails, the tunnel in which locomotives run being large enough to give clearance to 30-ton double-truck steel ore cars. These cars are loaded at bins in the mine, and after loading are passed under a timber gauge which limits the height of the ore so as not to interfere with the trolley wire.

The hoists at the Y and Pilares shafts are duplicate as far as the electrical equipment is concerned. They are designed to lift an unbalanced load of 5500 lbs. at a speed of 525′ per minute with 250 volts at the motors; with an unbalanced load of 3000 lbs., the hoisting speed to be 600′ per minute.

The hoists are double drum geared hoists, which can be operated balanced or unbalanced, each drum being driven independently of the other by means of clutches.

The Y shaft hoist is a new one, with motors mounted on same bed plate as the drums.

The Pilares hoist is an old steam hoist which has been operated electrically for the past three years. The motors in this case are set outside the hoist frame on independent foundations and geared to the crank discs of the steam engine, crown gears having been shrunk and keyed on the discs. The connecting rods and eccentric straps of the steam engine are disconnected, but can be reconnected again in a very short time to run the hoist with steam. This has been done only once, not because of trouble with the electrical equipment, but through the lack of power at the generating station.

The motors are two compound wound street railway motors, rated at 68 H. P. for one hour run, geared directly to the secondary shaft of the hoist. They are operated in series parallel by means of a drum controller giving five positions with the motors in series and four positions with the motors in parallel. The change from the series to the parallel connections of motors is done by the bridge method, which does not open the circuit, and gives a practically constant torque during the change. This prevents jars on the hoist cables.

The rheostats are of ample carrying capacity and their resistance is so proportioned that with a light load, such as two or three men, the acceleration is not unpleasantly fast; with the maximum load the hoist does not start until the second step of controller is reached.

Compound instead of series motors were employed, to allow the motors to be used as generators, and act as brakes when lowering men into the mine. Although series motors would also act as generators under the same conditions, they would have to attain too great a speed before "picking up," and then would give a too quick retardation. When used as generators, the shunt winding of the motors is excited from the outside circuit, and the current generated by the motors is passed through their series winding to excite the field in the same direction as the shunt winding. This is done so that if the outside current fails while lowering, the cage accelerates a little but is not completely deprived of electric brake. The current generated by the motors is passed through the starting rheostats. There are seven steps on the controller; on the first one the motors are short circuited without rheostat, then the resistance is gradually increased to a maximum, the increased resistance corresponding to an increased speed. The maximum resistance is such as to limit the lowering speed of a full cage of men to a set maximum speed which cannot then be exceeded. The first step of the controller gives a speed of about 60' per minute with a cage full of men.

The lowering of men into the mine is the most important work of this hoist; its operation is the reverse of the ordinary steam hoist. With a steam hoist the men are lowered "on the brake" and the steam kept as a reserve to stop the hoist in case of accident to the brake, while with the electric hoist, the hand brake is kept in reserve.

When changing the hoist from steam to electricity, all but one of the operating levers were kept the same as before, even the reversing lever of the engine being used to operate the reversing switch of the controller. The lever operating the controller was the only one changed from the one operating the throttle, but the controller was made to operate with a regular lever as nearly as possible the same as the throttle valve instead of the regular controller handle. This was done to prevent as much as possible, false motions on the part of hoisting engineers.

This hoist has been in operation for three years, and has worked very successfully. Outside of a set of new pinions, armature bearings, and controller contact fingers, there have been no repairs to the electrical equipment, the commutators not even having been turned once. The acceleration is very smooth, and the electrical braking is a marked improvement over the hand braking. These results are, to a great extent, due to the use of motors and controlling apparatus of generous size for the work to be done.

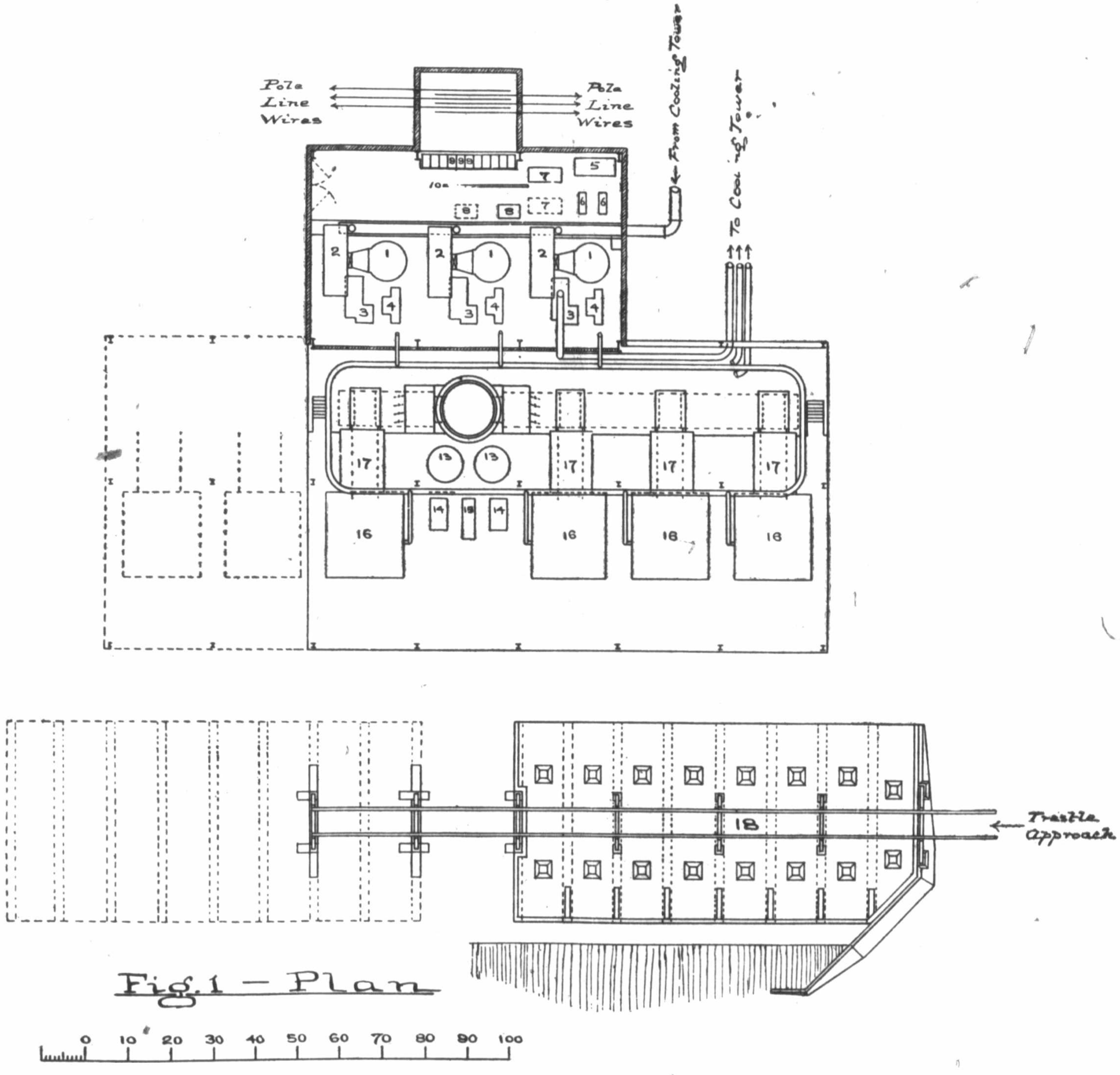
It may be interesting to give some tests of running efficiency of this hoist, obtained from the electric input of motors to total load lifted. The gears on the hoist itself are cast gears uncut, but worn smooth by several years of service. The weights given are only approximately correct, but error is not over 3%. The tests were taken when running unbalanced; the efficiency would be somewhat lower when running balanced, the friction being greater for the same total load lifted.

TOTAL LOAD.	HOISTING SPEED.	ELECTRICAL INPUT.	EFFICIENCY.
Lbs.	Feet per min.	E. H. P.	%
1300	656	46.6	55.3
1450	653	48.3	59.4
1900	634	60.0	60.8
2100	622	66.6	59.4
4100	586	107.0	68.0

With average care in starting, such as given by the Mexican hoisting engineers, the starting current does not exceed the running current by more than 25%.

REFERENCE NUMBERS TO APPARATUS SHOWN IN FIG. 1 AND FIG. 2.

1.—1000 K. W. Turbo Generator.
2.—Surface Condenser.
3.—Circulating Pump.
4.—Dry Vacuum Pump.
5.—Oil Filter.
6.—Oil Pump.
7.—50 K. W. Steam Turbine Exciter.
8.—50 K. W. Motor Driven Exciter.
9.—Oil Switch Cells.
19.—6600 Volt, Main Switch Board.
11.—230 Volt, Station Switch Board.
12.—75 K. W. Station Transformers.
13.—Feed Water Tanks.
14.—Motor Driven Feed Pump.
15.—Duplex Steam Feed Pump.
16.—435 H. P. Boiler.
17.—160 Tube Economizer.
18.—Coal Dock.



Pole Line Wires
Pole Line Wires
From Cooling Tower
To Cooling Tower
Trestle approach
0 10 20 30 40 50 60 70 80 90 100

Fig. 1 - Plan

Fig. 2

Sectional Elevation