Niagara Falls
100,000-Hp. Development

By JOHN L. HARPER
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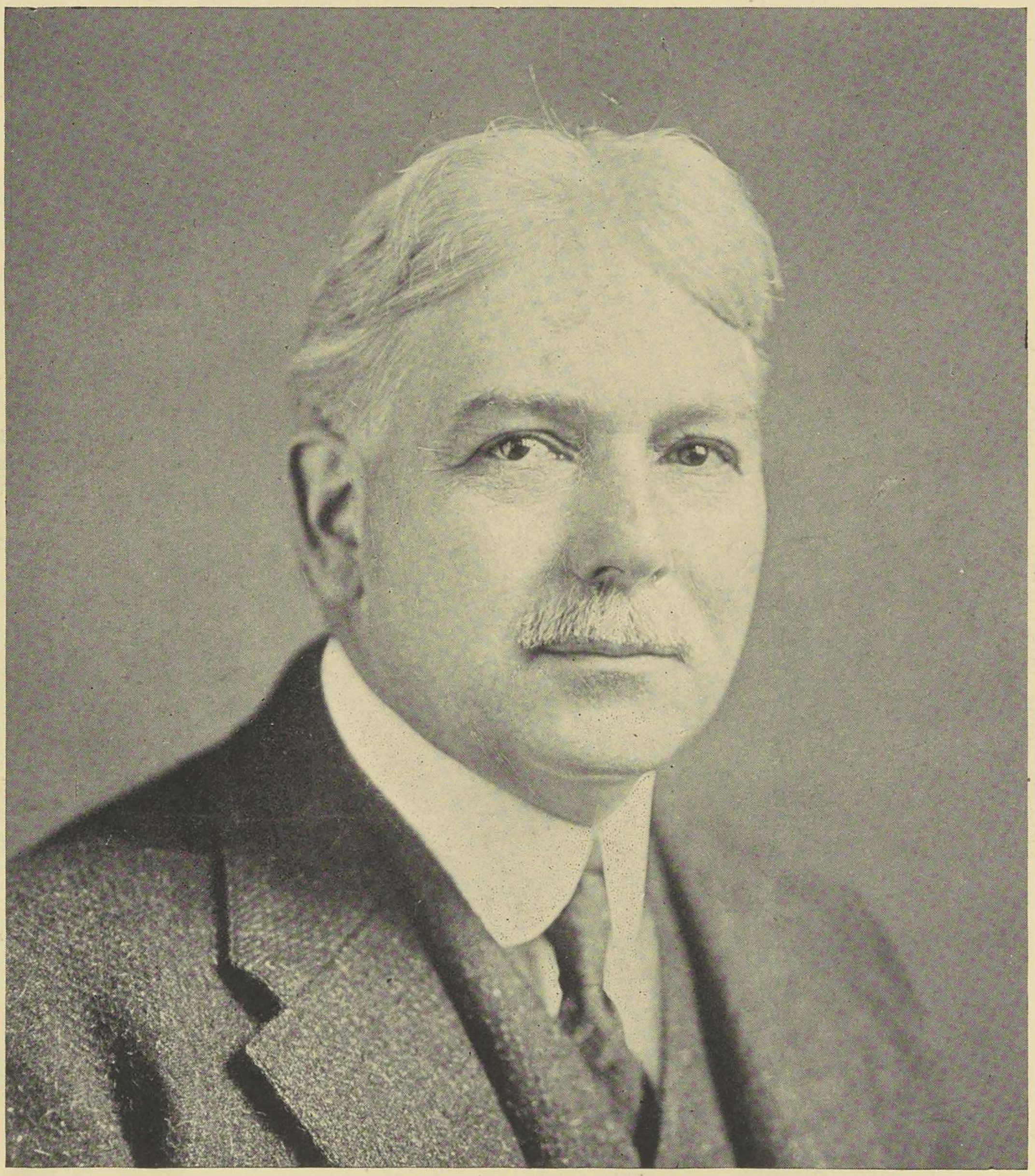


John Lyell Harper

The engineering genius back of the power developments at Niagara Falls whose resourcefulness has made it possible to use Niagara's waters without marring its beauty

THE most famous power development in this country, from the standpoint both of the engineering it represents and the service it renders to industry, is situated at Niagara Falls. This work stands as a monument to the genius of John Lyell Harper, whose name is as inseparably linked with it as is the wealth of the well-known Schoellkopf family that has made that development possible. It is due wholly to Mr. Harper's vision and engineering judgment that there stands today on the American side a mammoth station of 250,000 hp. where in 1902 there was a total rating of only 14,000 hp. The recent addition of 100,000 hp. which is described in this issue, built as a war need in record time and at a remarkably low cost, is the latest product of his engineering ability. In developing Niagara Falls Mr. Harper has devoted much study to ways and means to preserve the scenic beauty of the great cataract.

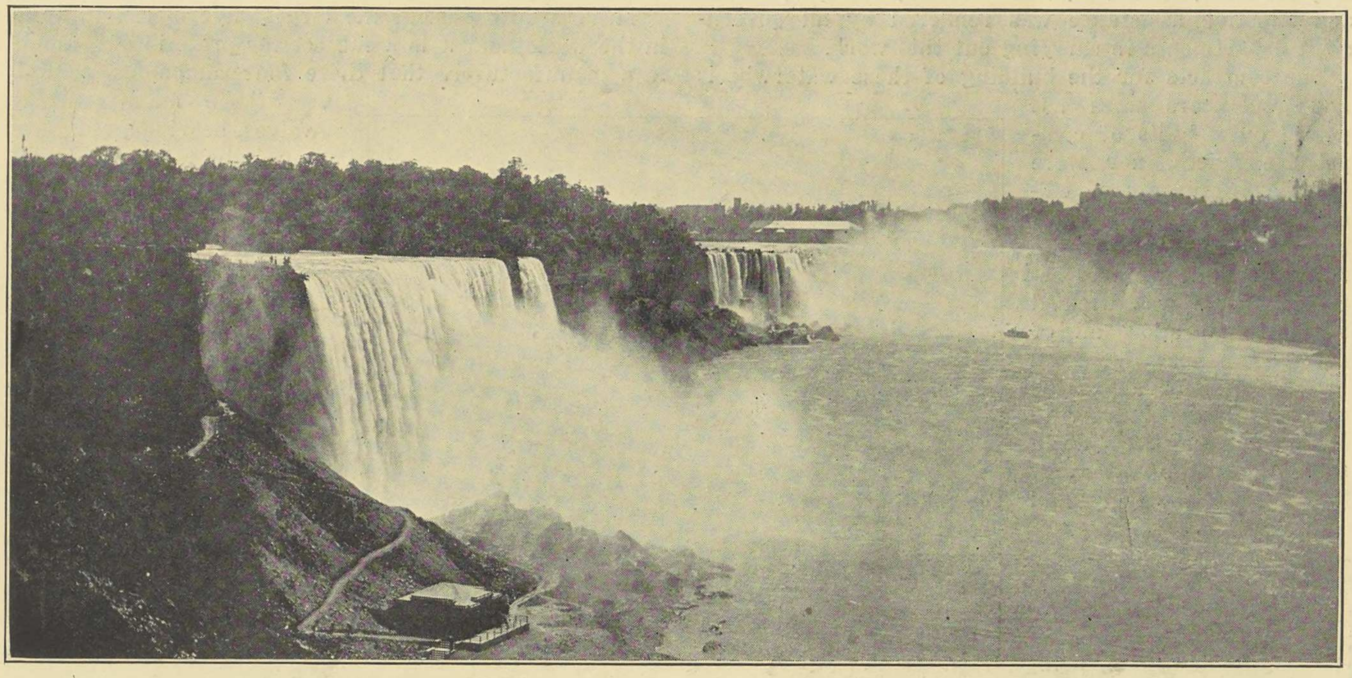
Besides his responsibilities as vice-president and chief engineer of the Niagara Falls Power Company, Mr. Harper has made scientific investigations of the applications of electric service in the electrochemical and electrometallurgical industries at Niagara Falls and has developed and patented several electric furnaces. In all his work he has maintained high engineering standards and ideals and has done much to stimulate manufacturers to turn out the highest grade of product rather than simply to meet specifications. One outstanding accomplishment was increasing the over-all plant efficiency from 65 to 90 per cent.

Mr. Harper was born at Harpersfield, N. Y., in 1873 and was graduated from Cornell University with the class of 1897. He first took up practical work with the Union Electric Company at Seattle, Wash. A year later he became associated with the Twin City Rapid Transit Company and the St. Croix Power Company of Wisconsin and spent three years in central-station design and operation. In 1902 he joined the engineering staff of the Hydraulic Power & Manufacturing Company at Niagara Falls, becoming its chief engineer two years later. Under the stress of war needs, the federal authorities brought about the merger of the power companies at Niagara Falls, and it is a fitting tribute to Mr. Harper's vision and ability that the developments of the consolidated companies were placed in his hands and that in 1919 the responsibility of vice-president was added. Mr. Harper works with his head, his heart and his hands, and, great as his past achievements have been, it is safe to say that his labors at Niagara Falls have only begun.

Niagara Falls 100,000-Hp. Development

Although Built Under the Stress of War-time Conditions, the Niagara Falls Power Company's New 100,000-Hp. Extension Embodies the Latest Word in Hydraulic and Electrical Development — Reliability of Operation and Maximum Efficiency Given Chief Consideration

By **JOHN L. HARPER**
Vice-president and Chief Engineer Niagara Falls Power Company



WHEN the war came and shells and guns and ships and motor trucks and phosphorus and gas were found vital to the existence of the nation and its allies, our government functioned through representatives whose minds appreciated values at Niagara other than in thundering vibrations and clouds of spray, wonderful as both may be in times of peace. There was no hesitation on the part of the directors of the war in first restricting Niagara power to the manufacture of basic materials and then demanding further development of power so that the production of these materials might be increased. All parties interested in power development at Niagara Falls were asked to submit plans and propositions for a "rush" development of the remaining water available for diversion under the treaty with Great Britain. From these competitive plans one of those presented by the Hydraulic Power Company of Niagara Falls was approved by the War Department as that which would produce the largest amount of power in the shortest time and at the same time be a proper and efficient power development after the stress of war had passed.

The plan approved by the War Department required the use of all the water to which the various operating companies at Niagara Falls had proprietary rights. To unify these rights it was obviously the easiest way to consolidate all the power companies, and upon suggestion of the War Department such consolidation was undertaken. The Niagara Falls Power Company, Hydraulic Power Company of Niagara Falls and Cliff Electrical Distributing Company were consolidated under the name of the Niagara Falls Power Company, the control and management of the consolidated company resting in the former owners of the Hydraulic Power Company.

Scope of Development

In the early part of May, 1918, authority was received from the Secretary of War with orders to proceed with the development in accordance with the approved plan under the supervision of an officer of the Corps of Engineers. The scope of the work carried out under this plan included the deepening of the intake from the Niagara River, the development and installation of improved ice-deflecting booms, the deepening of the Hydraulic Canal through the city of Niagara Falls, the construction of a new forebay, and three slope tunnels for taking the water from the forebay to the edge of the river in the middle basin, where the power plant was constructed as an extension to Station No. 3, the former Hydraulic company's plant, now known as the Hydraulic plant.

Three hydro-electric units were designed, to be equal in size and to have a combined output at the highest efficiency of 100,000 hp. In view of the peculiar conditions that existed on account of the war, and in order to secure quick delivery, the contracts for the manufacture of the waterwheels and generators were distributed as follows: One complete hydro-electric unit to the Allis-Chalmers Manufacturing Company, two waterwheels to the I. P. Morris department of the William Cramp & Sons Ship & Engine Building Company, one generator to the General Electric Company and one generator to the Westinghouse Electric & Manufacturing Company.

On account of the urgent need of this work by the War Department, A-1 priority orders were given by it to the builders for the obtaining of materials necessary for manufacture and construction, and sympathetic and effective assistance was rendered by all government departments in carrying out this work.

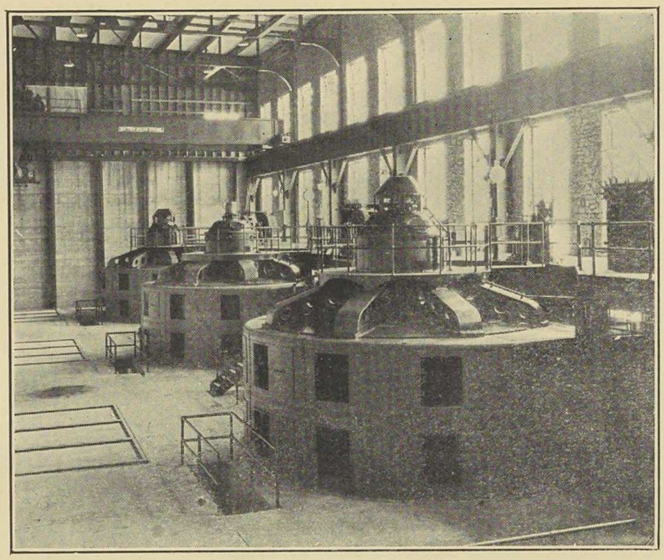
The contracts for the building of these waterwheels and generators were not placed on a basis of competitive prices, nor were specific guarantees of efficiencies exacted. As all of the power companies on the American side were to become one, it was deemed advisable to allow all of the larger manufacturers of this class of apparatus to have an opportunity to show what they could do in the production of these new units, which were expected to be the last word in hydro-electric design. All of the manufacturing companies approached their tasks with enthusiasm and patriotic endeavor to produce the best, and now, when all three of these units are in operation, it is impossible to say that any better apparatus could have been constructed under the most minute specifications and inspection. All of these companies not only co-operated fully with the War Department and the power company in meeting with dispatch the emergency requirements of rush production, but at the same time gave such careful and efficient attention to the whole design and manufacture that the resulting machinery was of the highest class known to the art. Although the machines are of different manufacture, the builders co-operated to produce similarity in their exteriors, thus giving a uniform and pleasing appearance to the station.

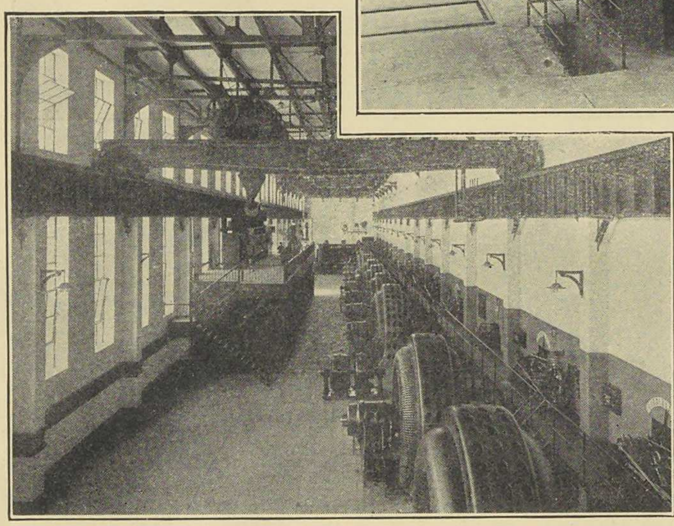
Although the official efficiency tests have not as yet been completed, it is apparent from those already made that the hydraulic efficiency will equal or slightly exceed 93 per cent, and that the efficiency from forebay to the switchboard will be over 90 per cent. The units have each demonstrated their ability to operate continuously at 40,000 hp., although the combined operating station output is considered as 100,000 hp.

These are at present the largest hydro-electric units in the world, and it is a subject for pride in our American manufacturers that these four companies, as well as those manufacturing valves, bearings, etc, have mutually taken this step in advance without failure in any particular.

The construction work was carried out in the face of unusual obstacles in procuring both labor and materials, yet in all cases the manufacturers of the principal parts of the apparatus lived up to their agreements as to time of completion. If the construction and installation had been pushed with the same vigor after the armistice was signed as it was before, it is probable that the first unit would have been put in operation in fourteen months after the word was given by the Secretary of War, but, under the reduced schedule as to progress, the first unit was not put in operation until nineteen months after authority was received to proceed.

The writer wishes to express his appreciation of the loyalty and efficiency of the engineering and construction staffs of the Niagara Falls Power Company, which were obliged to make the plans at the same time that the work was in progress, and whose ability and efficiency may be measured by the fact that in spending about $8,000,000 less than $1,000 was wasted in changes





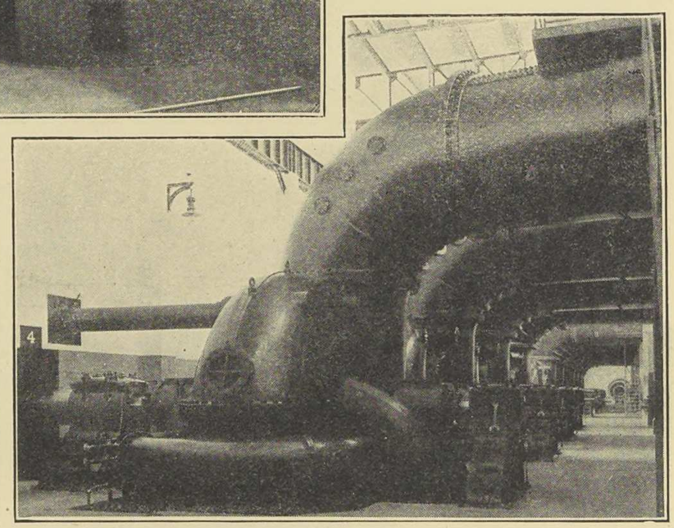


FIG. 1—THE NEW AND OLD AT NIAGARA NO. 3

At the top are the three new generators rated at 37,500 hp. but capable of developing 40,000 hp. Their magnitude is indicated by comparing them with the desk appearing just above the top of the nearby unit. In the lower left-hand view is a long hall of horizontal shaft generators driven by waterwheels on the opposite side of the wall. These wheels are shown in the right-hand view. All of these units are in the Hydraulic Plant No. 3, which is shown in Fig. 5.

of plans. In addition to those engineers who have contributed to this symposium and installments which are to follow it is desired to express appreciation of the efficiency and co-operation of Ross R. Coddington, general superintendent, whose aggressive and efficient personal direction of the construction work made possible the balance and speed with which the various parts of the work were completed in proper co-ordination without sacrifice of quality or perfection in workmanship. Also Benjamin F. Lee, operating superintendent, whose resourcefulness and experience overcame all obstacles in operating the older plants of the system during the interference of both mechanical and electrical construction by the building of this extension.

General Engineering Problems Involved in the Development

Steps Taken to Assure Ample Water in Winter—Vertical Units Allow for Large Fluctuations in Tailwater Elevation—Study of Draft Tube Requirements

By George R. Shepard

Assistant chief engineer Niagara Falls Power Company

At the time of the United States' entry into the war the Niagara Falls Power Company was entitled to draw from the Niagara River not to exceed 8,600 cubic-foot-seconds (240.8 cu.m. per second) and the Hydraulic Power Company was entitled to 6,500 cubic-foot-seconds (182 cu.m. per second). Very soon thereafter the need for power for war industries became so great that the War Department issued additional permits to both companies to cover the maximum output of the apparatus

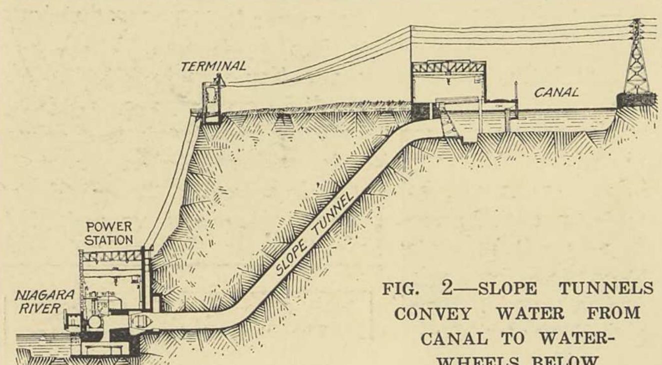


FIG. 2—SLOPE TUNNELS CONVEY WATER FROM CANAL TO WATER-WHEELS BELOW

then installed. After the merger of the two companies and the agreement of the consolidated company to proceed immediately with a new development, a permit was issued for the entire amount of water available at Niagara Falls under the treaty, or 19,500 cubic-foot-seconds (546 cu.m. per second). Fifteen thousand one hundred second-feet (422.8 cu.m. per second) of this could be utilized by the normal capacity of the existing plants, leaving a balance of 4,400 cubic-foot-seconds (123 cu.m. per second) for the new development.

The total diversion can be obtained continuously because the Niagara River is the natural outlet of a drainage area of about 300,000 square miles (750,000 sq.km.), making the variation of the river flow from normal comparatively small, although there is a small seasonal variation. Variations of greater amount are caused by winds and occasionally by ice jams but last only for a short period of time. Therefore, except for severe ice conditions, the river fluctuations are not an operating problem, nor will they be until there is considerably more diversion.

The combination of extremely uniform flow and a fixed maximum diversion limit placed the company in a position where load factor was, as it still is, the controlling economic element. Unless the company maintains continuously its maximum diversion, there is a certain

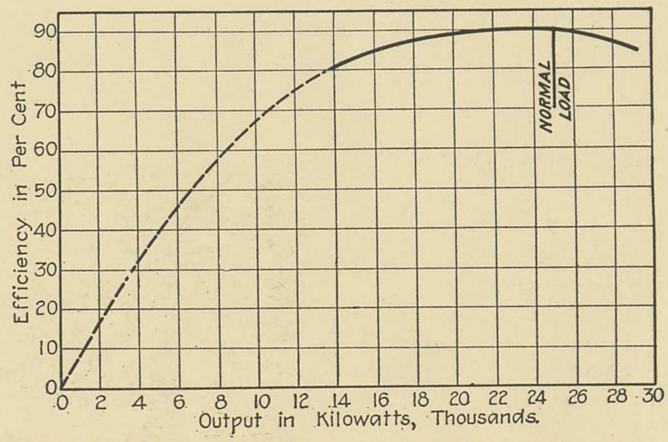


FIG. 3—AVERAGE OVER-ALL HYDRAULIC PLANT EFFICIENCY AT DIFFERENT OUTPUTS

amount of energy absolutely lost not only to the company but to the country in general. If the Niagara load were combined with a steam plant, economy would require a reversal of the usual custom and a supply of the base load by the hydraulic plants and the peak by the steam plant. It seems therefore that Niagara power is economically suited for industries requiring a continuous twenty-four-hour load and that any service with an inherently low load factor represents an economic waste.

The dire necessity for extreme speed in the development of power to meet the war demand for electrochemical products decided the power company in utilizing as far as possible its existing development to facilitate the new development.

The existing development consisted of a surface canal 100 ft. wide and 15 ft. deep, passing from the upper

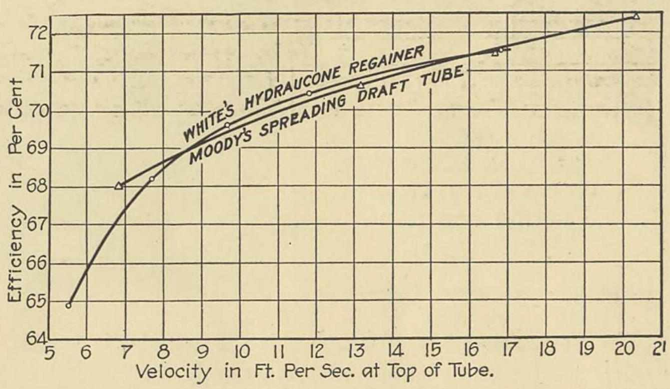
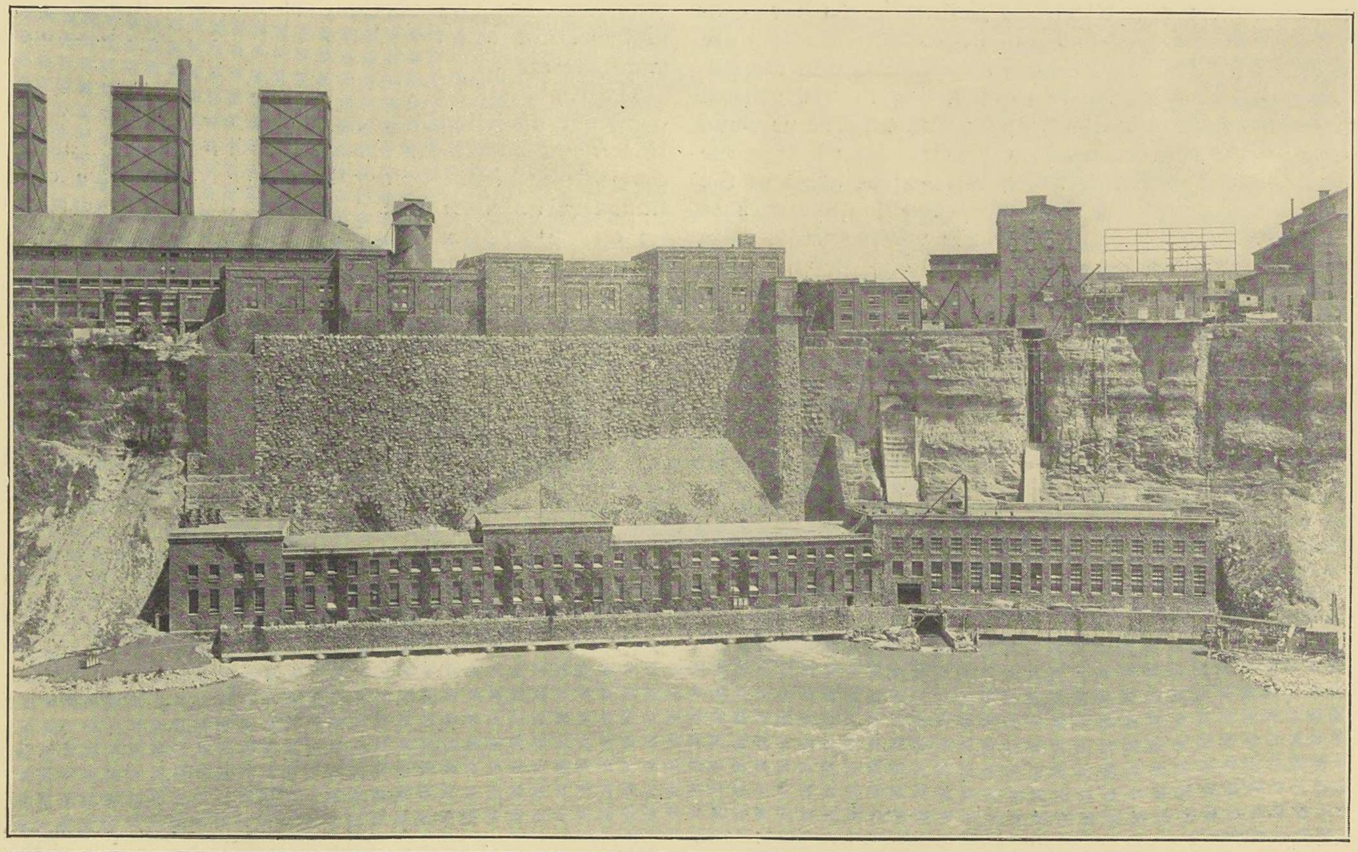
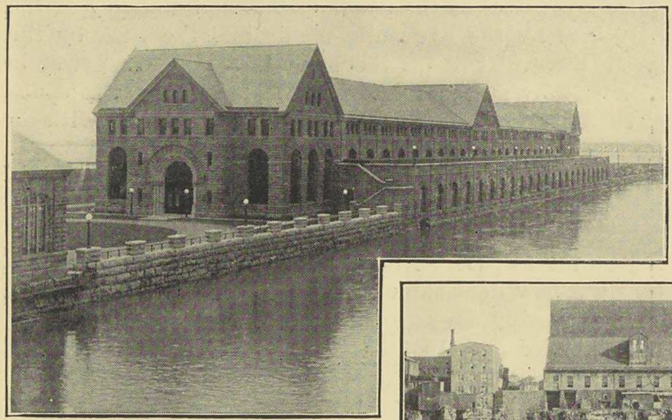


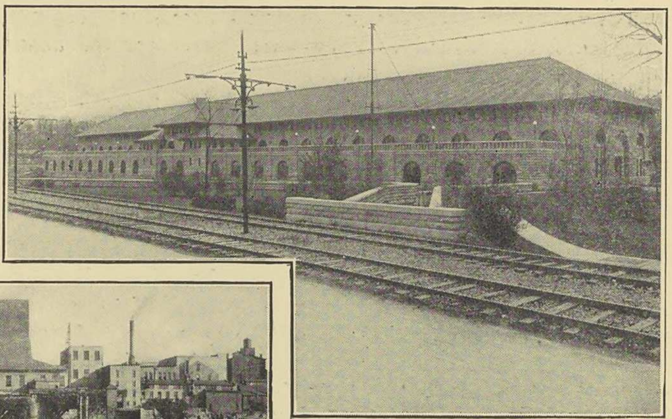
FIG. 4—EFFICIENCIES OF TWO TYPES OF DRAFT TUBES USED AT DIFFERENT RATES OF DISCHARGE

river through the city about 5,000 ft. to a forebay overlooking the high bank of the lower Niagara River. At this point is Station No. 3, which took water from the canal through thirteen steel penstocks built outside of the cliff, though now concealed from view by a face wall.

The water was delivered under a 212-ft. head to thirteen horizontal turbines of 10,000 hp. each.







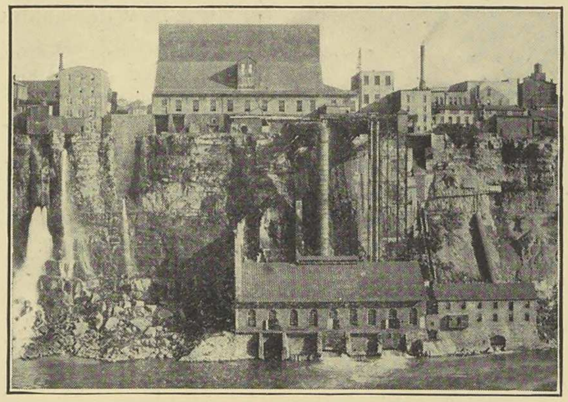


FIG. 5
FOUR OF THE NIAGARA FALLS POWER COMPANY'S STATIONS WHICH ARE TIED TOGETHER

The upper view shows the Hydraulic Plant, the right end of which contains the three new 37,500-hp. generators. Below at the left is one of the Niagara Plants (No. 2). At the right is the Canadian Niagara Falls station. The inset at the bottom is Station No. 2 of the old Hydraulic Power Company.

The new extension of Station No. 3 was built immediately upstream from the existing plant. It consists of three 15½ ft. penstocks opening directly from the canal through a new forebay and passing through the limestone rock at a general slope of 45 deg. to the power house built as an extension of the old power house just above the lower river level. Here are installed three vertical units of 37,500 hp. each. Along the river side of the building at the level of the thrust bearing deck of the generators is the operating gallery.

At the point where the power company takes its water, the Niagara River is a broad stream, and the main channel is near the Canadian side. Between the main channel and the company's intakes there is a broad stretch of water intersected with submerged reefs and ridges and having a depth of from 4 ft. to 14 ft. (1.2 m. to 4.2 m.) at the mean stage of water elevation.

The stream never freezes solidly over its entire width, and the outer line of the solid shore ice remains in approximately the same place from year to year.

One engineering problem involved in the new development was to obtain the normal supply of water for the power plants during the winter period of low temperatures and severe ice conditions. The company's engineers had studied this problem for twenty years and were prepared with the proper solution. A deep channel about 200 ft. (60 m.) in width was dug from the company's inlet outward to the edge of the ice line. Commencing at the intersection of this channel with the ice line, a series of piers were built, running upstream in the general direction of the ice line but gradually working in toward the shore. Floating booms were placed from pier to pier. About half way between this row of piers and the shore another row was placed, extending in the same direction and supporting floating booms in the same manner as the outer row. See Fig. 10.

This system has been in operation through one exceptionally severe winter and has proved entirely satisfactory. The booms have kept out the ice floating down

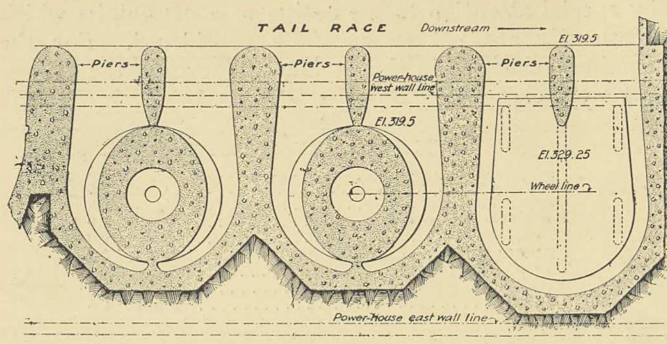


FIG. 6—HORIZONTAL CROSS SECTION THROUGH THE TWO TYPES OF DRAFT TUBES EMPLOYED

the river, and what small amounts actually formed inside the booms have been broken up from time to time in small quantities by the company's ice-breaking tugs and allowed to flow down the canal, where they were disposed of through the spillway gates.

Prior to this extension the canal was 100 ft. (30 m.) in width and varied in depth at the high-water period of the year from 15 ft. to 22 ft. (4.5 m. to 6.6 m.). In order to get sufficient water through the canal to run the added equipment it was necessary to enlarge the cross section. The canal runs through the most thickly settled portion of the city, and it was impossible to acquire property rights to widen the canal, so that the only possible thing to do was to deepen it. Drilling, blasting and dredging seemed to be the only practical method, although the proximity of large buildings introduced an element of risk which made extreme caution necessary.

The canal is spanned by eight bridges, having a clearance above the water surface of from 6 ft. to 15 ft. (1.8 m. to 4.5 m.), which prohibited the use of the ordinary type of dredge, but the long experience of the company's general superintendent with this class of work had evolved a dredge model that accomplished the work without any undue difficulty.

SELECTION OF WHEELS

The experience of the power company in former developments led to the adoption in 1906 of the horizontal-shaft units for the plant then being designed. However, in 1916, when most of the preliminary engineering on the present extension was undertaken, the Kingsbury

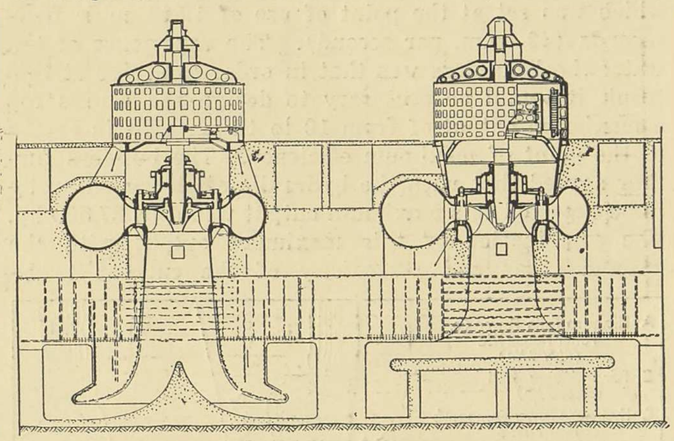


FIG. 7—CROSS SECTIONS THROUGH TWO TYPES OF WATERWHEELS USED SHOW DIFFERENCES IN DRAFT TUBES

and General Electric thrust bearings had reached a stage of perfection that eliminated the engineering problem in connection with the supporting of the weight of the rotating parts of the unit. These mechanical difficulties having been eliminated, the efficiency of the unit became the deciding factor, and the vertical units were used as offering the best opportunity for the development of a high efficiency. This type also made possible a vertical discharge and eliminated one 90 deg. bend in the draft tube.

Furthermore the surface elevation of the water in the lower river fluctuates through a vertical range of about 30 ft. (9 m.), so that the vertical design of unit offered the only means of getting the waterwheel runner low enough to get the full benefit of the low-water stages and at the same time have the electrical machinery high enough to be safe from damage during high-water stages. The available head obtained by this arrangement varied from 210 ft. to 220 ft. (64 m. to 64.6 m.), the mean being 215 ft. (64.3 m.).

Having determined the head, the maximum safe specific speed for the Francis type of runner was at

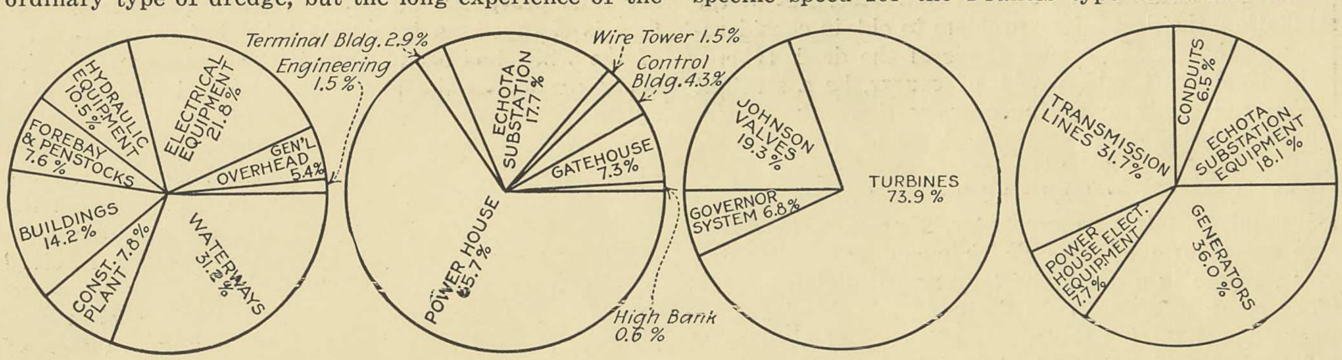


FIG. 8—SUBDIVISION OF CAPITAL INVESTMENT IN NIAGARA FALLS EXTENSION

A—Subdivison of expenses for entire extension, including power plant, transmission and substations. B—Subdivision of investment in buildings. C—Subdivision of investment in hydraulic equipment. D—subdivision of investment in electrical equipment for entire extension. The low engineering expense was due to employing men who were thoroughly familiar with existing conditions and who were thoroughly experienced along lines for which they were responsible. Note that the waterways constituted over 31 per cent of total investment.

once known and gave a rough idea of the limitations of speed and load for each unit. There was available for development 4,400 cubic foot-seconds (123 cu.m. per second), and the problem was to determine the number and size of units which would most efficiently develop that amount of water. Consideration of this feature and the rough limitations set by the specific speed led to the selection of three units as the proper number to use. The number of units being fixed, the next thing was the point of maximum efficiency for each single unit, which was set at the point of use of 1,500 cubic foot-seconds (42 cu.m. per second). The experience of the waterwheel builders was that in order to arrive at this result it would be necessary to design the wheels for a maximum output of from 10 to 12 per cent in excess of the point of maximum efficiency. The builders further agreed that with the hydraulic efficiency naturally to be expected this maximum output would be 37,500 hp. The combination of this maximum output with the specific speed and periodicity of the current to be

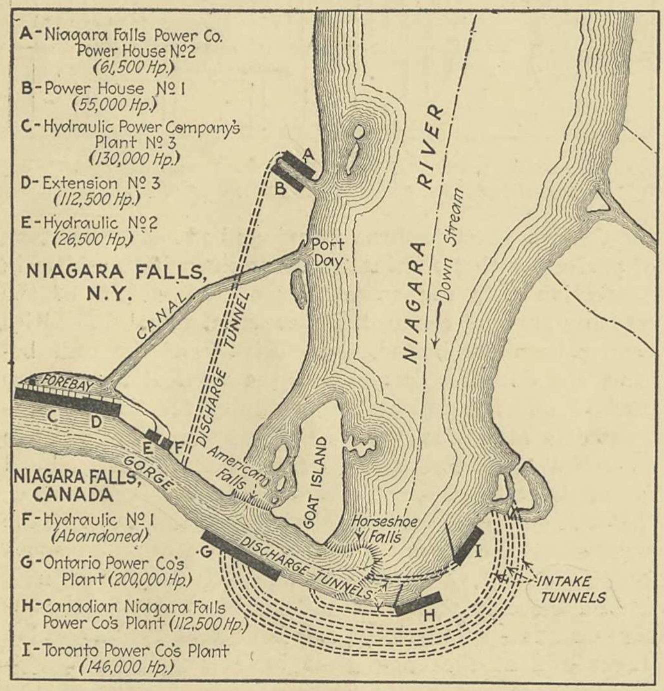


FIG. 9—LOCATION OF STATION NO. 3 EXTENSION WITH RESPECT TO OTHER PLANTS IN THE NIAGARA FALLS SYSTEM

generated fixed the speed of the unit at 150 r.p.m per minute.

Having determined the over-all characteristics of the installation, the first minor problem to obtain consideration was that of the proper shape of the draft tube.

The ideal draft tube would, of course, be a straight tube of uniformly enlarging cross-sections, the expansion angle being in the neighborhood of 4 deg. This ideal shape of draft tube is impracticable in most installations on account of the prohibitive cost of the excavation required. It was necessary, therefore, to determine some form of tube which would accomplish the same purpose in a much shorter vertical distance.

The company's engineers designed and developed an apparatus for testing the regain efficiency of a series of model tubes, and, after a long series of experiments on many different models, decided on the White hydraucone and a somewhat similar form of tube designed by the I. P. Morris department of the William Cramp & Sons Ship & Engine Building Company as offering the best practical solution of the problem.

Hydraulic Design and Efficiency of Units and Plant

Large and Easy Waterways Provided—Two Types of Draft Tubes Selected—New Method of Testing Wheels

BY N. R. GIBSON
Hydraulic Engineer Niagara Falls Power Company

EFFICIENCY was the underlying principle upon which the design of Station No. 3 extension was based, and to this end hydraulic losses were reduced to a minimum by providing large and easy waterways and by special attention to the design of some details which frequently are not so carefully considered. For the nominal velocities in the various waterways, the following were chosen:

	Ft. Per Second
Canal	4.5
Forebay	1.5
Through racks	1.8
Penstock entrances	3.0
Penstocks	8.0
Entrances to turbine casings	17.3
Top of draft tube	20.0
Exist from draft tube	5.0
Tailrace	3.5 to 4.5

With these velocities the resulting hydraulic losses from forebay to tailwater, exclusive of turbine efficiency, has been found to be approximately 2 ft. at normal load, or less than 1 per cent total average head available.

In collaboration with the designers of hydraulic turbines, considerable attention was given to the designs of draft tubes, and after experimenting with about twenty-five draft tube models of various designs two types were finally adopted and constructed in the power-house foundations. The right hand view of Fig. 7 shows the hydraucone regainer patented by W. M. White of Milwaukee; the left view shows the spreading draft tube patented by Lewis F. Moody of Philadelphia. The efficiencies of these two tubes, as shown by Fig. 4, were practically the same, and both gave results which were far in excess of the efficiency of any other model of equal dimensions.

The effect of these draft tubes is to maintain flow parallel to or radially from a central axis, with a gradual diminution of velocity until the velocity of discharge is finally reached. Such designs allow free play for the whirls in the water as it leaves the runner until the velocity of whirl has been greatly reduced. Large losses are thus prevented which occur when the direction of flow is changed, as in a bent tube, before the velocity of the whirl has been reduced. The passages are also designed so that the hydraulic friction losses throughout the tube are reduced to a minimum.

So far as can be ascertained, the adoption of these draft tubes has been fully justified by the results attained, such as the direct gain in efficiency and the freedom from excessive vibration of the machinery.

The efficiencies of the hydraulic turbines received particular consideration, but no guarantees were exacted from the manufacturers. Instead, each manufacturer agreed that "In lieu of any guarantees of efficiency the contractor will use its best engineering talent and skill in the design and construction of the turbine, to the end that the highest attainable efficiency may be secured. It is expected, but not guaranteed, that the combined efficiency of the turbine and generator will be as high as 90 per cent."

With this ideal constantly in mind each contractor has put into the work the best design, material and workmanship of which he was capable, and more than the expected efficiency has been attained.

Provision for testing the wheels in place was made by building a testing chamber around the base of the slope tunnels so that Pitot tubes or other equipment might be readily installed. While tests of the wheels may be made by using Pitot tubes and chemical gagings, it has not been possible to have such tests carried out up to the present time. However, complete efficiency tests have been made by a new indirect method of water measurement recently invented by the writer. This method, sometimes called the "pressure-time process,"* utilizes the relation between velocity change and rise of pressure, and by means of specially designed apparatus* there is produced a diagram, called the pressure-time diagram, from which the mean velocity in the conduit may be calculated. The apparatus, which is attached to a small piezometer tube tapped into the wall of the penstock at any convenient point, records on a sensitized film or paper the changes of pressure that occur in the penstock with respect to time. The changes of pressure are produced by the simple process of closing the turbine gates, or in some cases the Johnson valve.

The procedure for a test by this method may be briefly described as follows: The turbine gates are put on hand control, and steady conditions of load on the unit are maintained for several minutes until the flow in the penstock has become as uniform as possible. Readings of headwater and tailwater elevations are taken in the usual manner, and the pressure head at the entrance to the turbine casing is observed by gage or piezometer, so that allowance may be made for the loss of head in the penstock. Measurements of the generator output are taken by calibrated wattmeter and auxiliary instruments, and, if the unit is separately excited, ammeter and voltmeter readings of the exciting

*Patents applied for by N. R. Gibson.

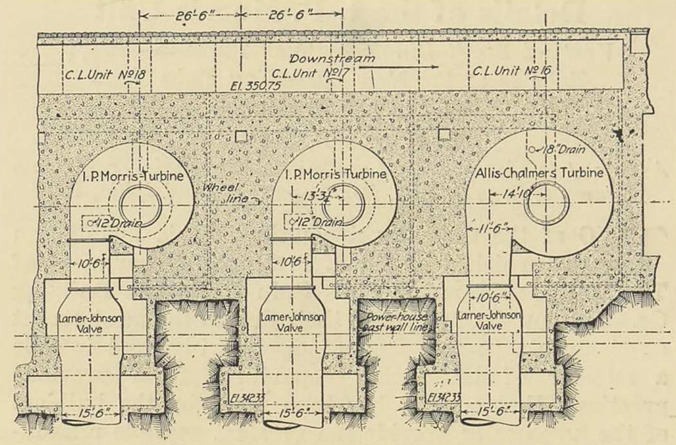


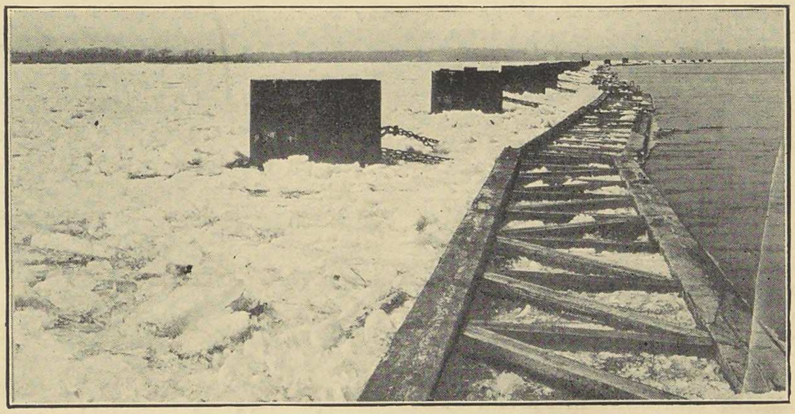
FIG. 11—HORIZONTAL CROSS SECTION THROUGH THE THREE NEW WATERWHEEL FOUNDATIONS

current are also obtained. When conditions have been steady for several minutes the turbine gates are closed gradually by operating the hand-control of the governor. During the closure the load thrown off the generator is taken up by the other units operating in synchronism with it. At the same time the Gibson apparatus makes its record of the changes of pressure that occur in the penstock. From this record may be calculated the mean velocity of the water in the penstock prior to the shutdown. Having determined the velocity, the discharge is readily computed, and after allowing for the known efficiency of the generator the turbine efficiency is calculated in the usual manner.

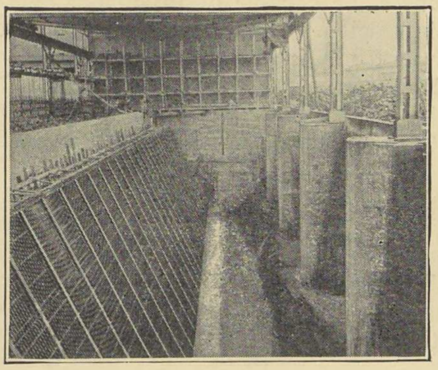
From these tests it has been determined that the turbine efficiencies are in excess of 90 per cent from half gate to full load, reaching in each case a maximum of 93 per cent.

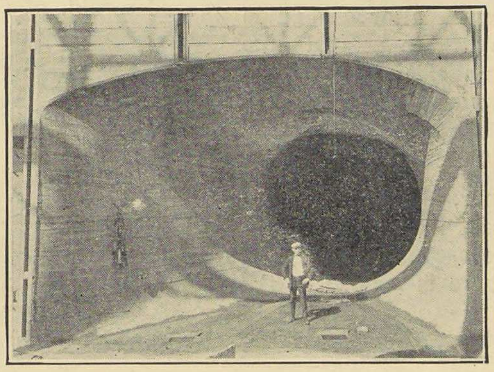
The average combined efficiency curve, including losses in penstock, Johnson valve, turbine and generator, is shown in Fig. 3. It will be noted that at normal load the efficiency from forebay to switchboard is 90 per cent.

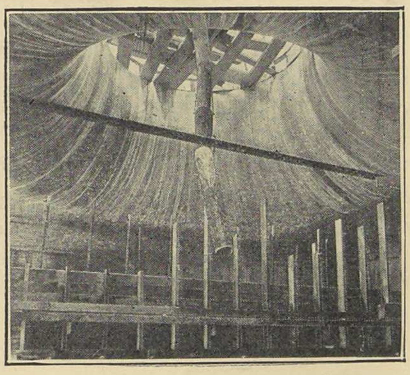
FIG. 10 PROVISIONS FOR HANDLING LARGE VOLUMES OF WATER USED BY STATION NO. 3 WHICH, WITH EXTENSION, HAS RATING OF 250,000 HP.



At the top are ice diverters which have been anchored near canal intake to keep the waterway free of ice. Below, at the left, are the intake racks for the new units. The racks are removed when slush ice is flowing. The flaring mouthpiece of one penstock shown in the middle view looms up like a cavern back of the man shown. At the right is a view from the draft tube looking up toward the outlet of one wheel.







Details of the I. P. Morris Unit

Vertical Shaft Single Runner Turbine—Draft Tube Is of the New Spreading Tube Type —Governor Regulation

BY LEWIS F. MOODY

Assistant to vice president and consulting engineer William Cramp & Sons S. & E. B. Company, Philadelphia, Pa.

TWO of the three turbine units in this installation were furnished by the I. P. Morris Department of The William Cramp & Sons Ship & Engine Building Co. These units involve in their design the most recent developments in this field of engineering, and include a number of interesting departures from previous practice. Every effort has been made by the builders of the turbines to provide the greatest possible reliability in operation and maximum obtainable efficiency.

The turbines are of the vertical shaft single-runner type, having cast-iron volute casings imbedded in the concrete of the power-house substructure. They operate at 150 r.p.m., and are designed to develop maximum efficiency when operated under an effective head of 213.5 ft. and discharging 1,500 sec.-ft. of water.

Taking up first the hydraulic features, it may be noted that the engineers of the power company working in co-operation with the engineers of the turbine builder have exercised every care to provide an efficient water passage from the point of entrance from the forebay into the penstock to the final point of discharge to the draft tubes into the tailrace. Preliminary tests have shown a very small loss of head in the penstocks, and indicate that excellent hydraulic conditions have been secured at all points in the water passage.

Before entering the turbine the water passes through a large Johnson valve. In passing through this valve the velocity of the water is gradually increased, the penstock diameter being reduced at the outlet of the valve to a value equal to the diameter of the inlet to the turbine casing so that the velocity of discharge from the Johnson valve is maintained at a constant value between the valve and the turbine. Owing to the construction of the turbine casing of cast iron, it has been possible to preserve smooth surface contours for the internal surfaces of the casing and to avoid all local disturbances in the flow due to abrupt changes of direction or irregular surfaces.

The diameter of the intake to the turbine casing is 10 ft. 6 in., involving a velocity of 17.3 ft. per sec. and a velocity head of 4.66 ft., which represents 2.18 per cent of the effective head of the turbine. The casing is designed for a gradual acceleration of velocity as the water passes around the volute. The casing is stayed across the distributor by ten curved vanes cast integrally in a cast-steel speed ring forming a part separate from the casing and built in halves. The vanes of the speed ring line up with alternate guide vanes, when the guide vanes are in the normal gate position corresponding to maximum efficiency. There are twenty movable guide vanes or wicket gates.

SPREADING DRAFT TUBE

After passing through the runner, the water enters a straight conical draft tube of cast iron built in sections. From the lower end of the cast-iron section of draft tube the remainder of the tube is molded in the concrete substructure.

The draft tube is of a new type, the "spreading draft tube." The design of this tube has been carefully calculated and verified by many tests of experimental models both under conditions of smooth streamline flow in the water entering the tube and under the actual conditions of flow experienced when the discharge is received from a runner. In the design of this tube it has been the object to turn the water as smoothly as possible along paths of gradual curvature from the vertical to the horizontal direction, and to preserve symmetry about the turbine axis to a point where the velocity has been reduced to so low a value that only a small amount of velocity head remains in the water. Care has been taken to maintain a gradual decrease in the velocity by properly varying the transverse area of the passage at all points in the tube, in order under all conditions of operation to avoid the formation of eddies or disturbances at any point in the stream.

In many earlier installations under high and medium heads, particularly those involving long penstocks, the use of elbows in the draft tubes has resulted in severe vibration of the water column in the penstock and turbine. This vibration is believed to be due to the formation and breaking down of eddies in the draft tube. Another advantage of the form of tube used is the ability of such a draft tube to regain the energy of whirling components of velocity in the water leaving the runner. This property of the tube is of value in increasing the efficiency under part-gate and over-gate conditions, and in increasing the margin of power beyond the point of maximum efficiency of the turbine. Preliminary tests of the turbine indicate that both of these advantages have been realized, and in actual operation the unit is remarkably free from vibration of any kind at all gate openings.

CAST-IRON RUNNERS AND CASING

The turbine runners are of cast iron, each one being in one piece. The runners are 10 ft. 6 in. in diameter in inflow. The specific speed of the runners is 158 metric or 35.5 in the foot-pound system. The throat of the runner or the diameter inside of the band is 9 ft. 10½ in. At normal discharge the corrected velocity of the water leaving the runner and entering the draft tube is 21.3 ft. per sec., corresponding to a velocity head of 7.0 ft., or 3.3 per cent of the effective head on the turbine.

Although the most valuable feature of the new draft tube is probably the elimination of vibration just mentioned, it is also estimated that this tube will improve the efficiency over that which could be obtained with tubes containing elbows by from 0.3 per cent to 0.4 per cent in the efficiency of the entire turbine under conditions if normal gate operation. The same type of draft tube when applied to turbines of high specific speed would, of course, be capable of producing much greater increases in efficiency than is possible in these turbines, which are of moderate specific speed. The final discharge velocity from the draft tube at normal gate is approximately 5 ft. per sec., corresponding to a velocity head of 0.175 per cent of the effective head on the turbine.

The turbine casing is of cast iron built in six sections. The use of a cast-iron casing, although involving a somewhat increased cost as compared to the use of plate steel, furnishes a superior design in the following respects: The casing is absolutely rigid and can be imbedded in the concrete so as to form a part of the substructure, and can be relied upon to transmit the loads imposed upon it without distortion. The resistance of cast iron to corrosion insures a long life for the casing, which is a matter of importance since the casing could never be replaced without dismantling all of the surrounding concrete substructure. The casing can be depended upon to be tight throughout the life of the plant, and there is no likelihood of local points of weakness being developed as in the case of a riveted structure. The casings have been subjected to hydrostatic pressure tests in the shops to a pressure of 120 lb. per square inch, which is well in excess of any pressure to which the castings can be subjected in operation during a quick gate closure resulting in water hammer. Another advantage of a cast-iron casing is the ease and speed with which it can be erected in the field. The heaviest section of the casing weighs slightly less than 60,000 lb.

The movable guide vanes are of cast steel, cast integrally with their stems. The guide-vane stems turn in bronze bushed bearings in the distributor plates and head cover.

Operating and Lubricating Mechanism

The operating mechanism is unusually rugged throughout, the guide-vane stems being of large diameter, the cast-steel operating ring extremely rigid; and the levers and other parts of the mechanism being made sufficiently strong to render the failure of any portion of the mechanism an unusual occurence even when trash becomes lodged between two guide vanes and the entire governor power is concentrated on two vanes. Renewable breaking links are provided to protect the other parts of the mechanism in case undue load should occur. The operating ring is supported on a ball bearing. It is turned by two operating cylinders which are bolted to pads or brackets cast on the turbine casing, thus making the entire operating mechanism self-contained with the turbine. The connecting rods between the operating ring and pistons are provided with adjustable ends of similar design to the connecting-rod ends used in steam-engine practice so that any wear may be taken up and lost motion avoided in the operating mechanism. The piston rod is provided with a bronze sleeve where it passes through the stuffing box in the cylinder head, and the rod is guided by a bearing supported in a guide bracket bolted to the cylinder.

For the lubrication of the operating gear, the Taylor system of lubrication is used, consisting of a central grease gun supplying a system of piping leading to each individual bearing, so that the admission of grease or oil can be controlled to each bearing individually by turning a separate cock at each bearing, the lubricant being forced into the bearing by air pressure admitted to the grease gun.

A special design of runner seals have been used to reduce the leakage around the runner and to assist in making the thrust relief effective. The seals are of the multiple or labyrinth design in which a series of contractions are interposed in the path of the leakage water alternating with enlargements in which the velocity of the leakage flow produced eddies and reduces the quantity escaping. This provision although effecting only a small percentage of the total energy when the turbine is new will be of material advantage in preventing a serious deterioration in efficiency after the unit has been some time in operation. The leakage

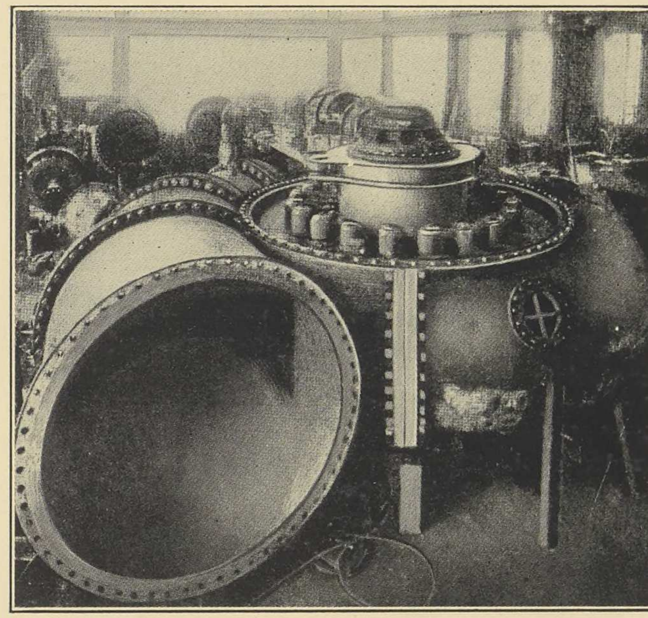


FIG. 12—I. P. MORRIS TURBINE ERECTED IN SHOP

above the runner passes through a cored space in the turbine head cover and is vented through the runner hub, discharging into the center of the draft tube. The seals are formed in renewable wearing plates. The distributor plates above and below the movable guide vanes are also renewable. At discharge from the runner the draft tube is lined with a renewable ring which may be replaced if corrosion should occur during the life of the unit.

The main shaft of the turbine is supported by a lignum-vitæ guide bearing in the turbine-head cover, and the shaft is provided with a renewable bronze sleeve where it passes through the bearing, seal and stuffing box. The bearing shell is split both horizontally and vertically to facilitate its removal. The equipment furnished with the turbine includes a set of brakes arranged to act upon the lower face of the generator rotor. These brakes consist of a series of shoes actuated by plungers, operated by air pressure. The operation of a brake is controlled from a cock mounted on the hand-control stand located close to the governor.

Governor Regulation

The turbine is regulated by a governor of the I. P. Morris double floating-lever type, belt driven from the main shaft of the turbine. The governor proper or the actuator and the separate hand-control stand are located on the gallery at the elevation of the thrust bearings mounted on top of the generators. The unit can therefore be operated from this point.

In order to avoid running a number of lines of the large governor piping from the operating cylinders up to the gallery with a consequent increase in the length of fluid column between the governor and the cylinders, resulting in increased inertia of this fluid column, the main governor valves are separate from the governor and placed on the level of the generator-room floor so that they are immediately above the operating cylinders.

The Taylor control system is used with these units. This involves the use of fluid-operated plunger valves of the Johnson type, by the operation of which the operating cylinders can be connected to either the governor or to the hand-control system. The plunger valves are located in a common casing with the main governor valve, which is located directly below the actuator, and the same casing supports a lower guide bearing for the governor spindle. All of the valves for shifting from governor to hand control and back again are controlled by a single lever mounted on the governor stand on the gallery. By a single throw of this lever a special control cock is operated which admits pressure to the plungers of the various Johnson valves and properly shifts the pressure and return connections from governor to hand control or vice versa. By this system, failure of the operators to manipulate the valves in proper sequence is avoided, thus avoiding loss of control of the unit between the time of its being taken off the governor and put on hand control. The entire operation can be carried out very quickly, which is frequently a matter of importance in station operation, and all loss of time required to open and close the series of valves by hand is avoided.

The separate hand control provided in addition to the governor contains separate valves and restoring mechanism by which the turbine gates can be operated through the pressure system, the gates being automatically maintained in any position corresponding to the setting of the hand wheel. By this means the unit can be operated on hand control with the governor and all of its valves thrown out of operation and made available for inspection and repair. A clutch is provided by which the governor head may be put out of operation without shutting down the unit so that all parts of the centrifugal mechanism can be made accessible. The centrifugal governor head is extremely powerful and is not influenced by slight changes of friction of the governor parts or other variation of conditions.

Among the members of the Cramp company's organization who have been responsible for the design of this turbine installation may be mentioned: H. Birchard Taylor, vice-president;John Overn, Jr., manager, I. P. Morris Department; Frank H. Rogers, hydraulic engineer; and R. E. Brunswick Sharp, assistant hydraulic engineer.

Design of the Allis-Chalmers Unit

Unit Developed 40,000 Hp. Under Test—Runner Is a One Piece Casting—Hydraucone Draft Tube Used

BY W. M. WHITE

Manager and chief engineer hydraulic department, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

THE hydraulic turbine forming Unit No. 16 of the extension to station No. 3 is rated at 37,500 hp. when operating at the normal speed of 150 r.p.m. under the normal operating head of 214 ft. and is designed to use 1,500 sec.-ft. when operating at best efficiency. The unit has recently been put under full load and actually develops at normal head and speed a capacity of 40,000 hp.

Unit No. 16, which is the first one installed and the first placed in operation, was designed and built by the Allis-Chalmers Manufacturing Co. at Milwaukee, Wis. Since the design of the entire Allis-Chalmers hydro-electric unit was under the control of a single group of engineers it was possible to consider the structure properly as a homogeneous unit and correctly proportion and correlate the various elements. Such proceedure was followed so that the completed machine possesses a unity not frequently met with in hydro-electric practice.

The design of the turbine embodies several new features of interest to water-power engineers, particularly the form of casing, governor, interconnecting barrel, brake support and draft tube used.

The water for the units in the new station is taken from the old Hydraulic Power Co. canal and is delivered to the unit through a 15½-ft. diameter penstock and controlled by Johnson valve located near the turbine. The discharge diameter of the Johnson valve is 10 ft. and to this is connected a short section of the feeder pipe which increases in diameter to 11 ft. at the entrance to the plate-steel circular section spiral casing surrounding the turbine and supplying water through guide vanes to the runner. The casing is made up of a multiplicity of conical sections of plate steel of gradually reducing cross-sectional area around the turbine. The plates are riveted to the flanges of a cast-steel speed ring which forms an integral part of the casing and the foundation of the turbine parts. The thickness of the plate steel of the casing at the 11 ft. diameter is ⅞ in. This thickness is reduced gradually to ½ in. at the smallest section of the casing. The roundabout seams of the casing are lap joint, double riveted and the longitudinal seams are lap joint, triple riveted, while the connection at the ends of the plate to the cast-steel speed ring is made by a triple row of rivets. The rivets are countersunk on the inside.

PLATE-STEEL CASING

Fig. 17 gives a view of the casing as erected in power house. There are about six thousand rivets in the casing which were driven by a No. 90 air hammer. The heads were formed by 1⅛-in. by 1¼-in. snaps. The casing was calked inside and outside. It was concreted in without an hydrostatic test. No leaks of any kind have developed about the casing. Those who are familiar with plate-steel work will readily understand that plate thickness of 1¼ in. can be readily worked so that a casing substantially of the size shown could be designed and constructed for heads up to 350 ft. without unduly stressing the material or sacrificing tightness and without going beyond normal practice obtaining in plate work of this nature. Above all, however, all uncertainties as to casting strains are eliminated and only strictly dependable material used. On account of the simplicity of the construction and low cost relative to cast iron this casing was made larger in diameter so as to reduce losses due to friction, thereby tending toward higher turbine efficiency.

Water is controlled from the casing to the runner by means of twenty cast-steel guide vanes. Each vane has pivots on each end for the support of the vane and for controlling its position. Each vane is operated by means of a lever secured to the extended pivot through a link connecting to the shifting ring located on the outside of the turbine. Each guide vane is held in position by two thrust bearings, one supporting the weight and the other resisting the upward hydraulic thrust of the stem through the stuffing box when the unit is in operation.

The thrust bearings are so adjusted that the guide vane is held in a central position between the distributor plates with fixed and equal clearances on each end of the vane; consequently there is no friction and no wear between the ends of the vanes and the distributor plates.

A stuffing box is provided about each vane stem and water is thereby prevented from flowing through the bronze bearings supporting the vane—a specially desirable feature in that silt and sand which would tend to rapidly wear the main supporting journal is not carried between the surfaces by leakage. Levers are keyed to the vane stems and attached to the shifting ring through an adjustable connection and links having a cross-sectional area so proportioned as to fail before a guide vane or its stem is strained beyond its elastic limit should a guide-vane passage become obstructed. Heavy plate-steel wearing plates line the distributor plate at each end of the guide vanes. Wearing bushings are embodied on the upper and lower distributer plates opposite corresponding wearing rings placed on the upper crown plate and the lower band of the runner.

RUNNER OF ONE CASTING

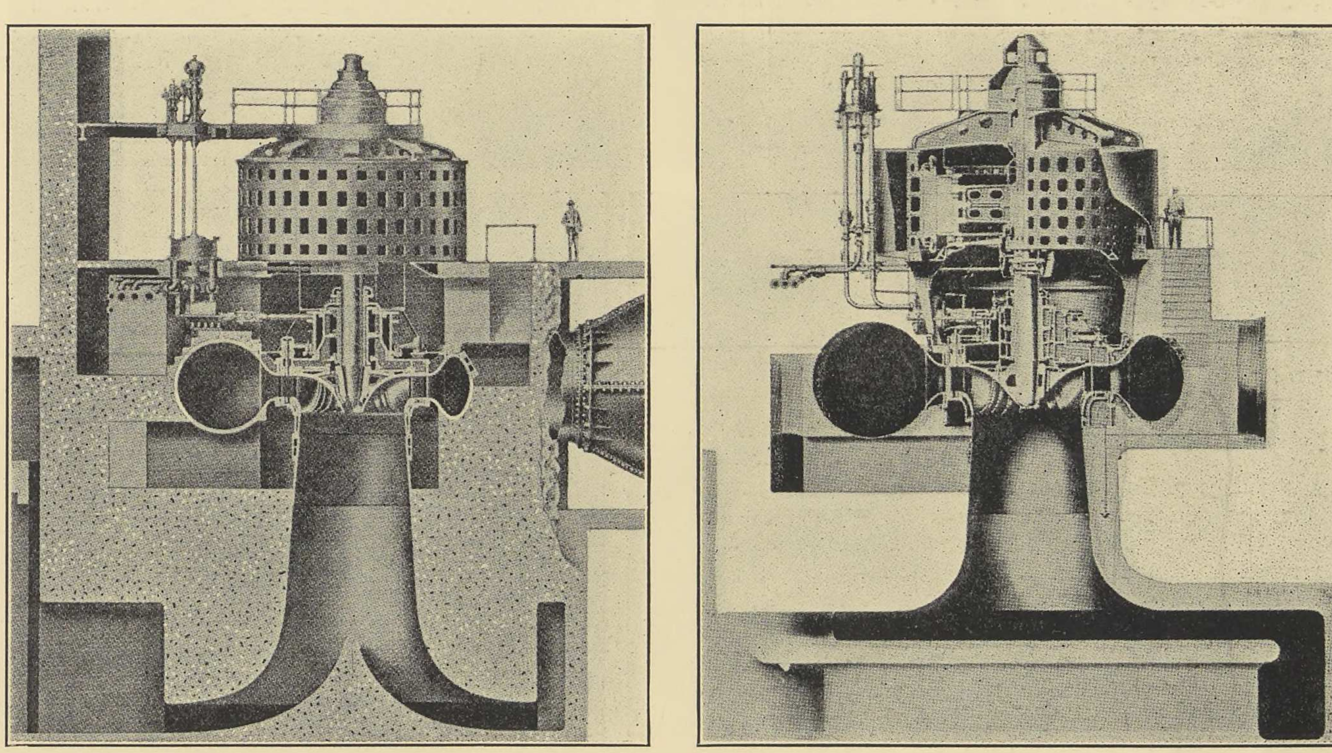
The runner is of grey iron in one casting made by means of fitted cores and is bolted to a cast-iron hub which is keyed to the tapered end of the turbine shaft and held in place by ring, key and keeper. Either a taper connection as here used or a forged flange on the end of the shaft upon which the runner is mounted makes a good construction, but where a water bearing is used, with a bushing on the shaft, the construction here used is the better one, as it enables the bushing to be made solid and therefore of less thickness and results in the lower peripheral speed for a given unit. The diameter of the shaft at the turbine guide bearing is 28 in.

The turbine guide bearing consists of lignum vitæ fitted into cast-iron blocks having the end grain of the lignum vitæ toward the shaft. The bearing of this unit is 5 ft. in length and is made in two parts for convenience in dismantling and ease of handling. The bearing is lubricated by water supplied from the headrace through fine strainers. Connection is also made to the city mains for use of filtered water during times when headrace water contains considerable silt and sand.

A feature which distinguishes Unit No. 16 from the other units is the cast-iron pit liner forming the turbine pit and transmitting the weight of the generator through this pit liner directly to the speed ring and through the vanes of the speed ring to the foundation. From a mechanical and design standpoint the value of this barrel can hardly be overestimated, tying together as it does all the major elements in which forces originate and from which they have to be transmitted. Interalignment of main working elements, i.e., generator, turbine and regulating cylinders, is permanently insured regardless of the behavior of the surrounding concrete.

The guide vanes of the turbine are controlled by means of water pressure on two pistons connecting to opposite sides of the shifting ring, inclosed by cylinders, mounted directly on the outside of the supporting barrel or pit liner. The mounting of the operating cylinders on the outside of the pit liner is unique and affords a clean design of the pit, as it keeps the governor pipes outside of the turbine chamber. This feature of design enables the cover-plate of the turbine to be removed by merely removing the pistons and crossheads and without disturbing the cylinders and governor piping.

An interesting feature of design is the governor equipment especially designed for this unit. The guide vanes are shaped to cause the smoothest flow from the casing to the runner and the position of the stems on



FIGS. 13 AND 14—TWO NEW 37,500-HP. UNITS OF THE NIAGARA FALLS POWER COMPANY

The units were built by different manufacturers (left, I. P. Morris wheel and Westinghouse generator; right, Allis-Chalmers unit) under the same general specifications. Generators are rated at 32,500 kva., 12,000 volts, and the units operate at 150 r.p.m. under 214-ft. head. Two types of draft tubes are shown—the spreading draft tube and hydraucone.

the guide vane body is such that the vanes will be in hydraulic balance when about one-third open. They will require considerable force to close the vanes from that point and considerable force to hold them in wide-open position under the high velocity of the water between the vanes, but both forces are minimized. The operating cylinders are 32 in. in diameter and the governor is designed for a normal operating pressure of 125 lb. so that the two pistons are capable of exerting 150,000 ft.-lb. when moved the full stroke from one end of the cylinder to the other. With a difference between the sides of the pistons equal to an operating pressure of 200 lb. and consequently by the usual method of rating governors, the governor of this unit has a capacity of 240,000 ft.-lb.

The operating pressure to the cylinders is controlled by means of a four-ported 12-in. diameter piston valve located in the governor stand. The pipe connecting the ports from the piston valve to the operating cylinders is 6 in. in diameter. This large diameter valve is necessary so that an axial motion of the valve of ½ in. will at normal pressure afford the area of opening required to pass sufficient water to force the operating pistons from one extreme to the other in two seconds of time. The main piston valve, above described, is moved axially by varying the pressure on each end of its body by means of another four-ported 3¼-in. diameter piston valve and this piston valve in turn is moved axially by varying the pressure on each end of it by a ⅞-in. diameter pilot valve. By means of the smaller piston valve the size of the pilot valve and consequently the force to be exerted by the flyball is materially reduced over what it would have to be were the valve omitted.

The edges of the ports and the edges of the piston valves and the pilot valves are so carefully made that under normal operating pressure that is practically no lost motion between the axial motion of the pilot valve and the axial motion of the main piston valve. Under slow motion of the pilot valve the main piston valve will follow with a lag of less than 0.01 in. and under the axial movement of the pilot valve of ⅛ in. in 0.01 in a second the maximum lag of the main piston valve would not exceed 0.02 in. By thus reducing the size of the pilot valve the force required to move it has been reduced to such an amount that it does not exert suffi-

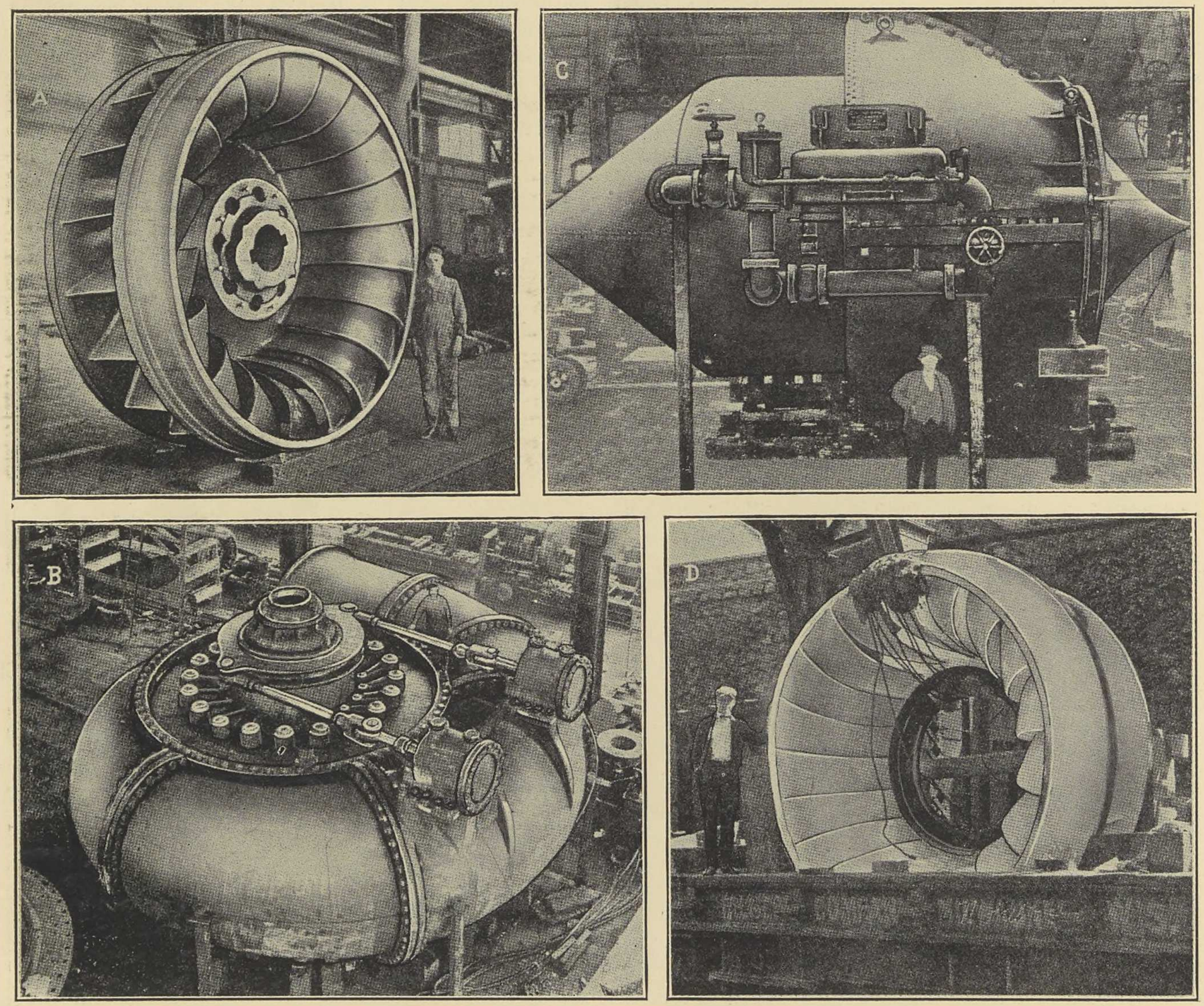


FIG. 15—REPRESENTATIVE VIEWS OF HYDRAULIC UNITS BEFORE ASSEMBLY

(A) and (B), runner and assembled unit of I. P. Morris construction. (C) Johnson valve for control of water in penstocks, and (D) Allis-Chalmers runner.

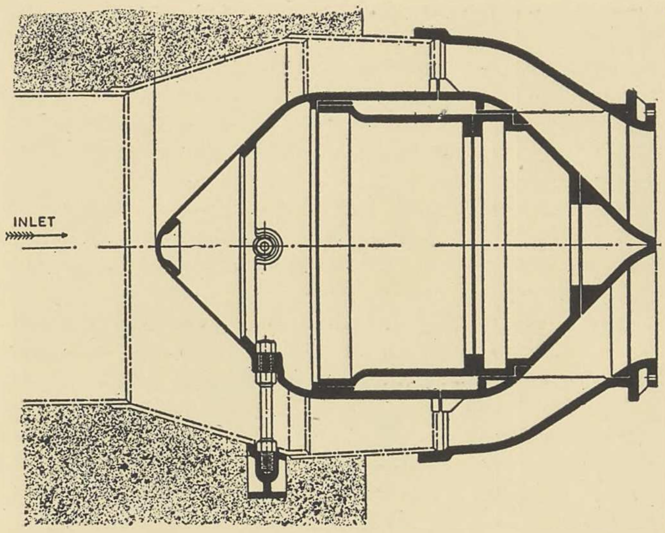


FIG. 16—LARGEST PENSTOCK VALVE IN WORLD

A Johnson hydraulic valve measuring 17 ft. x 24 ft. over all is installed at the bottom of each penstock close to the entrance to the wheel casing. The valves are balanced needle-type valves, having a movable plunger sliding in an internal cylinder. The plunger is of differential form, providing two operating chambers which are alternately exhausted to the air to move the plunger, the hydraulic pressure in the penstock furnishing the sole actuating force. Local or remote control can be used. The valve stroke may be set for any time up to a minimum of thirty seconds for a complete stroke in either direction. The valve can also be set to close automatically in case of a serious break in the wheel casing.

cient force upon the flyball mechanism to prevent the flyballs taking up their exact position corresponding to the speed of the unit.

It was thought that a turbine of this magnitude should be equipped with a flyball mechanism steady, positive and as near frictionless as possible. The directly connected flyballs embodied in the design of this turbine have met these conditions. The flyball mechanism consists essentially of a fixed collar clamped around the main turbine shaft and a movable collar held in position and away from the shaft by four sets of ball-bearing toggle joints located 90 deg. from each other. Two sets of toggle joints as incorporated in the design act as flyball weights. The outward motion of these sets is resisted by two adjustable springs being connected through ball bearings to each of the sets. Every toggle is fitted with a type of ball bearing preventing axial motion and consequently each set of toggles prevent endwise motion of the floating ring with respect to that set of toggles and as the two sets of toggles are at 90 deg. the movable collar is rigidly supported and prevented from moving in any direction except axially with respect to the main turbine shaft. It is a unique feature in governor flyball design that the floating collar has no support except through the motion-giving mechanism. This design of flyball, therefore, affords a means of imparting to the pilot valve such motion as is caused in the flyball by the variation in speed of the main turbine shaft and thus is avoided the disturbing motion introduced by belts and gears when the usual type of flyball is used. The motion of the movable collar located around the main shaft is transmitted to the pilot valve by means of levers, reach rods through sliding shoes resting upon an oil-inclosed bearing surface at the upper side of the movable collar.

The governor has been adjusted to close the turbine gates from wide open to completely closed in three seconds of time and to open them from closed to wide-open position in four seconds of time. It is expected that the rise of speed with 40,000 hp. suddenly thrown off the unit will not exceed 25 per cent. The regulation of the unit and the normal load conditions are remarkably steady and positive.

HYDRAUCONE DRAFT TUBE

The engineers of the Allis-Chalmers Manufacturing Co. at the time of first putting this unit into operation made a remarkable demonstration to show their confidence in the apparatus. The initial start of the unit was made solely from the station switchboard by closing the switch operating the control motor on the governor which moved the pilot valve causing the main turbine gates to open. This admitted water from the casing to the runner setting the unit in motion. When the unit had attained a speed of 90 r.p.m. the weights of the flyballs came into play and manipulated the pilot valve and regulated the unit perfectly at that speed. Without any adjustment in the governor being made the governor motor was manipulated from the switchboard and the unit brought up to a speed of 150 r.p.m. within ten minutes of the initial starting. The governor regulated the unit positively, steadily and perfectly under that speed.

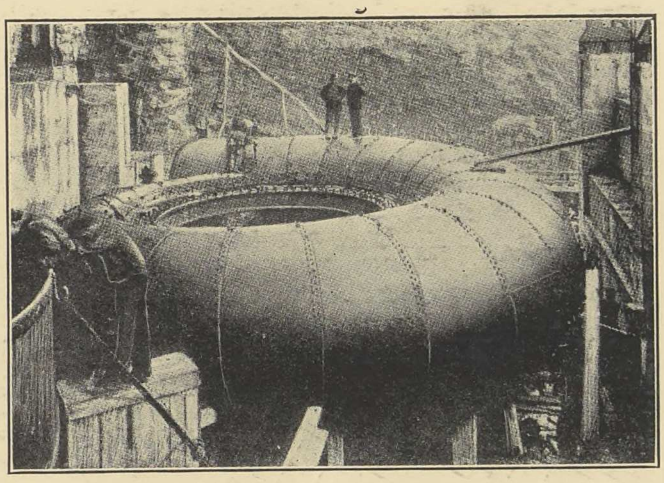


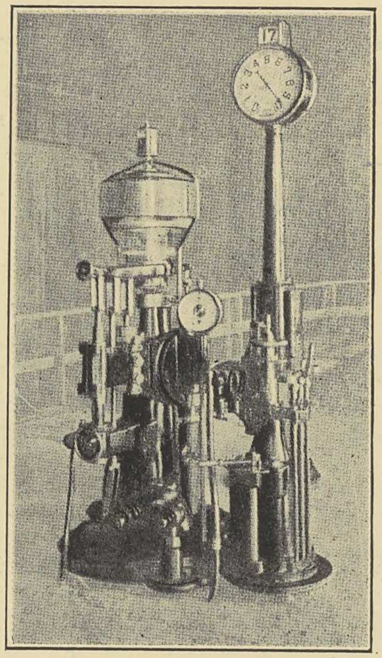
FIG. 17—ALLIS-CHALMERS TURBINE CASING ERECTED IN POWER HOUSE

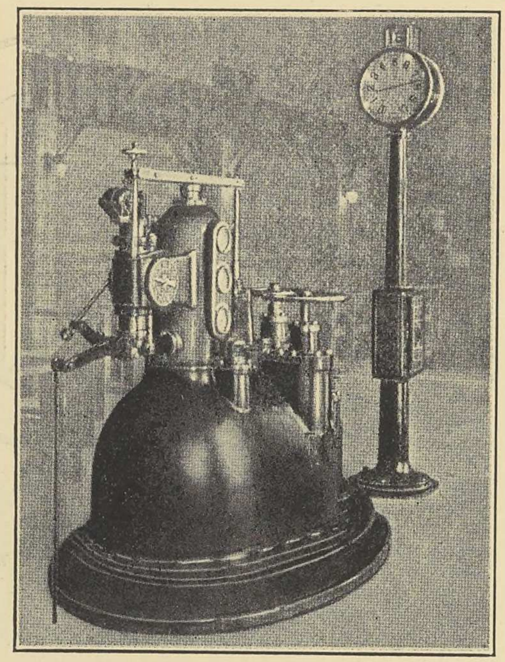
One of the greatest losses in hydraulic turbines is in the energy discharged from the runner. Efforts have heretofore been made to utilize this energy by transforming the velocity into pressure for maintaining below the runner greater vacuum than would normally result due to the elevation of the runner above tail water level, and thus in effect increasing the effective head on the turbine. The size of the units in water-power development have been increased until the diameter of the runner is large compared to the distance from the runner to the tail water level so that in large units it has not been found feasible to design the draft tube on account of the short radius of bend which will most efficiently utilize the energy discharge from the runner with an excavation of tailrace such as the owner is usually willing to make.

In Fig. 14 is an illustration of one form of "hydraucone regainer."

The word "hydraucone" has been coined to express the shape which a jet of water takes upon striking any given surface and includes the form from the point where this stream begins to make its turn to the end of the curvature. Consequently a hydraucone regainer was used which is a chamber having a general form which the jet of water would take upon striking the impinging surface except that the capacity of the chamber is gradually greater in area in the direction of flow than that required to just close the hydraucone. The radially extending passage also affords a means of regaining for useful effect the whirl of the water as it leaves the runner at partial loads. It is not within the scope of this article to discuss at length the hydraucone.

This unit has now been in successful operation for a sufficient length of time to show that all of the new elements embodied in its design are working as planned and that the complete unit is an unqualified success.





FIGS. 18 AND 19—GOVERNOR MECHANISM FOR I. P. MORRIS AND ALLIS-CHALMERS WHEELS

Structural and Equipment Features of New Niagara Plant

Piers and Booms Used to Keep Ice Out of Canal—Trash Racks Run Entire Length of Forebay Ice Skimmer at Forebay Inlet

BY O. D. DALES
Construction engineer Niagara Falls Power Company

STATION No. 3 of the Hydraulic Power Co., is located below the falls at the lower end of the canal passing through the city. It takes water from the canal through thirteen steel penstocks built outside the cliff—though now concealed from view by a face wall—and delivers it under 210 ft. head to thirteen horizontal turbines of 10,000 hp. capacity each. The canal was started in 1852 but was not put into operation until 1872. It has been enlarged from time to time up until 1912 when Station No. 3 was completed at which time it was 100 ft. wide and around 15 ft. deep and had an average flow of about 9000 sec.-ft.

The 1918-20 extension to Station No. 3 was built immediately upstream of the 1906 plant. It consists of three 15½-ft. penstocks taking directly from the canal through a new forebay and passing through the limestone rock at a general slope of 45 deg. to the power house alongside the old power house just above the lower river level. Here are installed three vertical turbines of 37,500 hp. each, connected to generators of a capacity of 32,500 kva. each, generating 12,000 volt, three-phase 25-cycle current when operating at 150 r.p.m. The recent operations comprised additional ice protection in the upper Niagara at the mouth of the canal, enlargement of the canal, to pass the required 13,200 sec.-ft., construction of the forebay behind a cofferdam holding back the canal, driving the penstock tunnels through rock, construction of the power house and erection of the hydraulic and electric machinery. The Niagara River, at the point where the company takes its water, is a

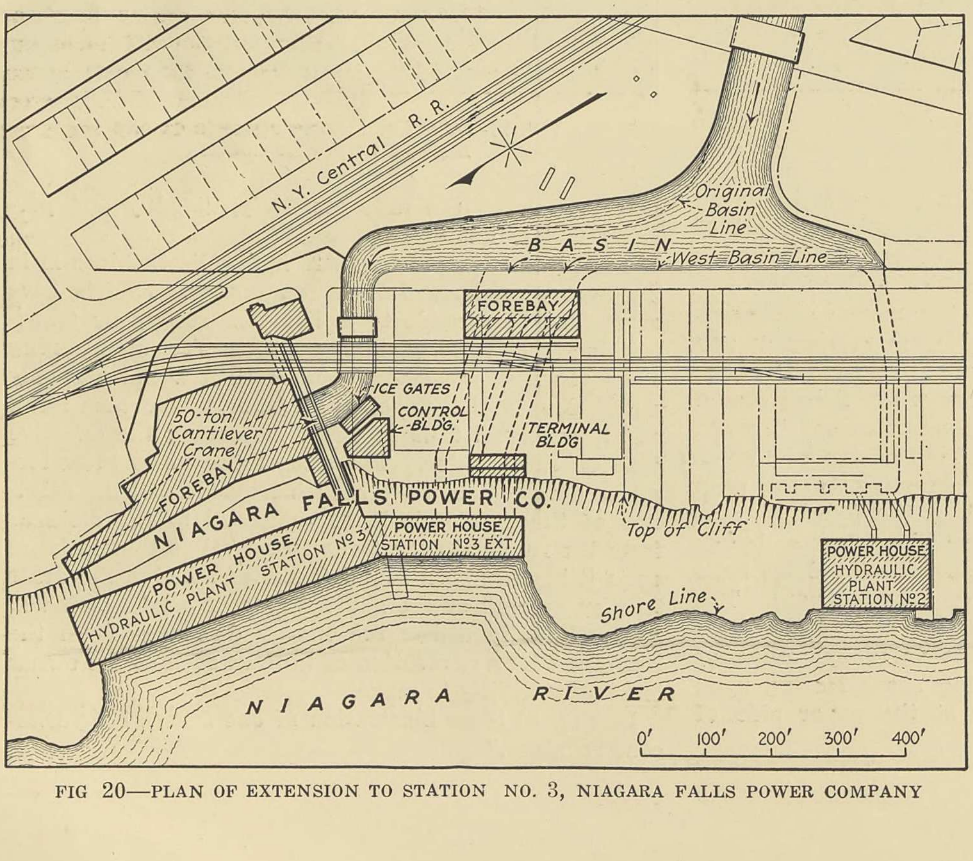


FIG 20—PLAN OF EXTENSION TO STATION NO. 3, NIAGARA FALLS POWER COMPANY

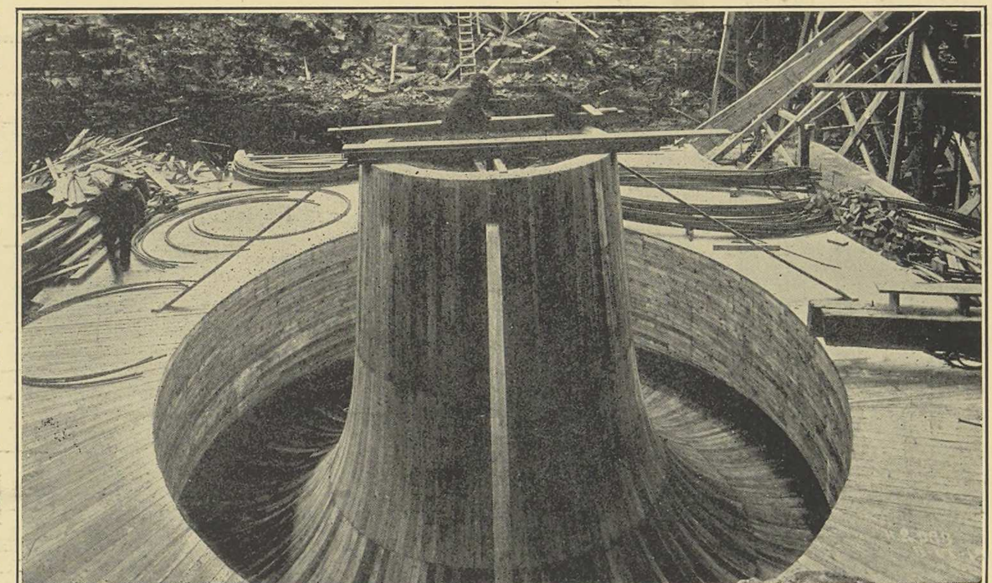


FIG. 22—DRAFT-TUBE FORMWORK FOR I. P. MORRIS UNIT

broad stream, and the main channel is near the Canadian side. Between the main channel and the company's intakes there is a broad stretch of water intersected with submerged reefs and ridges, and having a depth of from 4 to 14 ft. at the mean stage of the water elevation.

The engineering problem involved in the river work was to obtain the normal supply of water for the power plants during the winter period of low temperatures and severe ice conditions. The stream never freezes solidly over its entire width, and the outer line of the solid shore ice is located in approximately the same place from year to year. A deep channel about 200 ft. in width was run from the company's inlet outward to the edge of the ice line. Commencing at the intersection of this channel with the ice line, a series of piers consisting of steel sheetpile cylinders filled with concrete were built running upstream in the general direction of the ice line, but gradually working in toward the shore. Floating booms of truss frames were placed from pier to pier. About half way between this row of piers and the shore, another row was placed, extending in the same direction and supporting floating booms in the same manner as the outer row.

This system has been in operation through one exceptionally severe winter and has proved entirely satisfactory. The booms have kept out the ice floating down the river, and what small amounts actually formed inside the booms, have been broken up from time to time in small quantities by the company's ice-breaking tugs and allowed to flow down the canal where it was disposed of through the spillway gates.

In order to get sufficient water through the canal to run the added equipment it was necessary to enlarge the cross section. The canal runs through the most thickly settled portion of the city, and it was impossible to acquire property rights to widen the canal, so that the only possible thing to do was to deepen it. The canal, prior to the enlargement, was 100 ft. in width and varied in depth, at the high water period of the year, from 15 to 22 ft. The new section is of the same width but has been deepened uniformly to 20 ft.

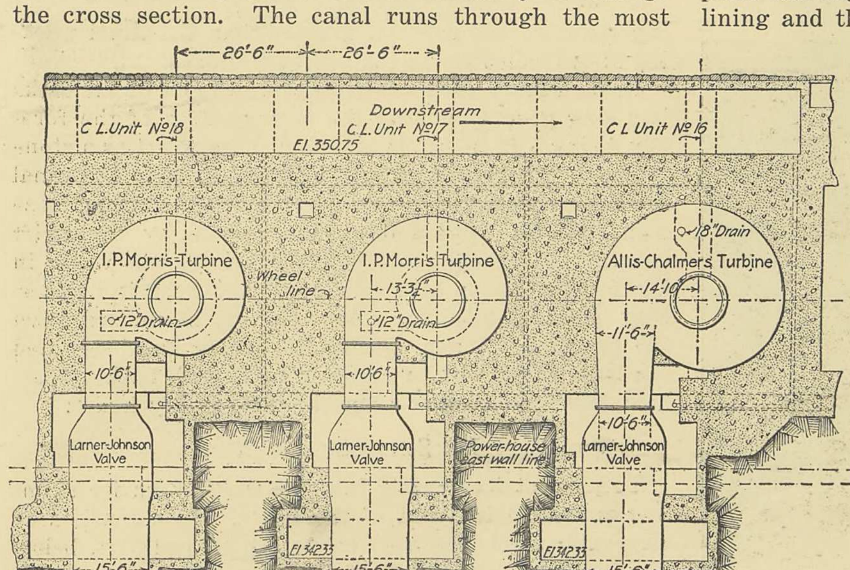


FIG. 21—HORIZONTAL SECTION THROUGH TURBINE SETTINGS

FOREBAY AND PENSTOCKS

The forebay is 154 ft. 7 in. long,, 75 ft. wide, and 26 ft. 3 in. deep below normal water. It is entirely lined with concrete. Running out of the forebay are three penstocks, which are concrete lined tunnels of 15 ft. 6in. in diameter. The entrance to the penstocks is a bell-mouth 18 ft. 9 in. high by 28 ft. long.

The penstock tunnels after leaving the bell-mouths turn downward at an angle of 45 deg. until they reach a plane at El. 353, which is on a line with the center of the waterwheels. They then run as horizontal tunnels out through the rock to the waterwheels in the power house. Of this horizontal part 76 ft. is composed of $1\frac{1}{3}$-in.-steel plate thoroughly riveted. The space between the steel lining and the rock is filld with concrete.

The valve for each unit was placed at the bottom of the penstock close to the turbine in order to save time when filling the penstock after the ordinary shutdown of a waterwheel. Stop gates were provided for the bell-mouth end as an extra precaution. These are merely large steel gates, three for each penstock, the center gate having a small by-pass wicket. These stop gates slide down in steel guides over the face of the bell-mouth. Steel lined grooves were placed in the face of the forebay wall to receive these stop gate guides.

Each of the three turbine casings is connected to its penstock through a Johnson hydraulically operated, electrically controlled valve. These valves which are the largest in the world, were furnished by the Larner-Johnson Valve and Engineering Co. The outer valve housing is

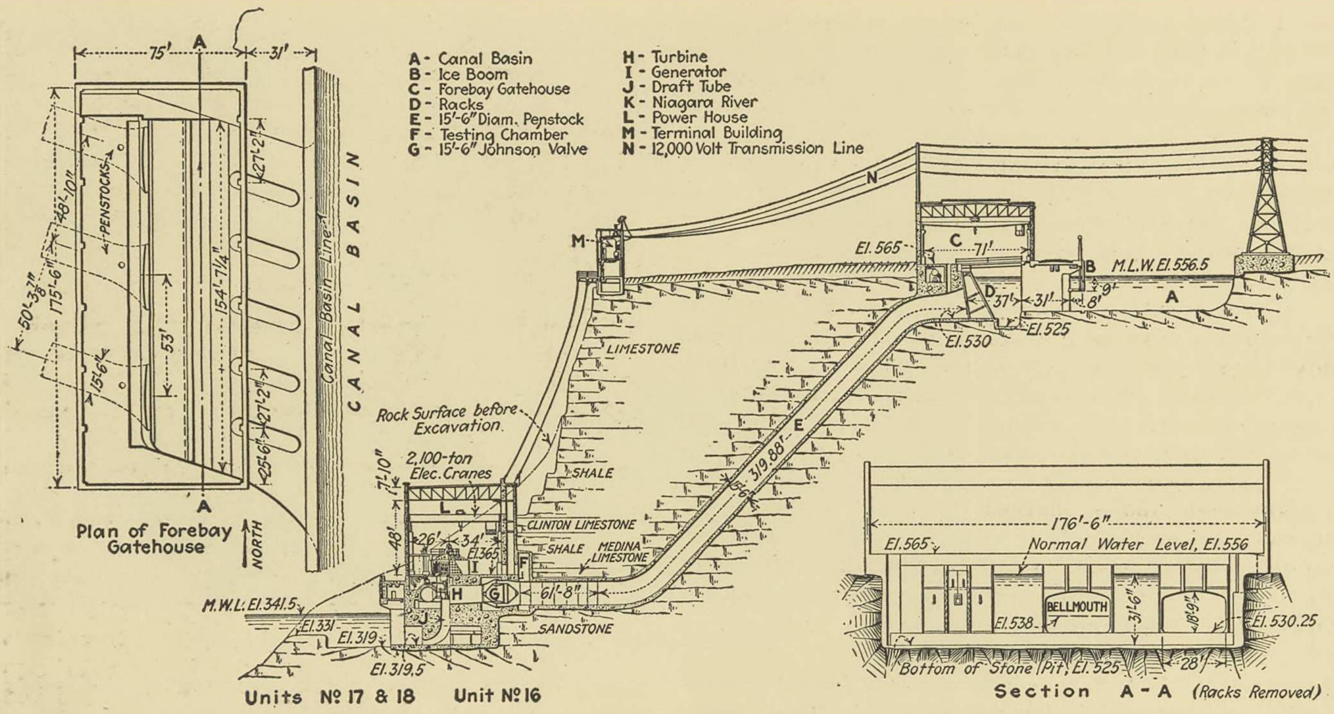


FIG. 23—CROSS-SECTION OF NEW STATION WITH THREE 37,500-HP. TURBINES AND STATION RATING OF 100,000 HP.

of cast steel and steel plate and is 17 ft. inside diameter through the body of the valve and tapers to 10 ft. 6 in. diameter at the outlet end. The entrance end to the valve housing is made of steel plate forming a flaring extension of the 15-ft. 6-in. penstock. The length of the valve is about 24 ft. Throughout the total length, approximately 24 ft., the area of the water passage is reduced without abrupt changes or sharp curves and the stream-line shape of the valve parts renders the hydraulic losses practically negligible.

Trash Racks and Stone Catcher

The trash racks which run the entire length of the forebay are composed of 4 x ½ in. flat steel bars spaced by cast-iron spreaders 4 in. centers. These racks are supported by a framework of steel designed with the assumption that the racks might become clogged and carry the entire hydrostatic pressure. The steel supports are designed to carry the entire head with a working stress of 100 per cent greater than the usual working stress called for in the ordinary design.

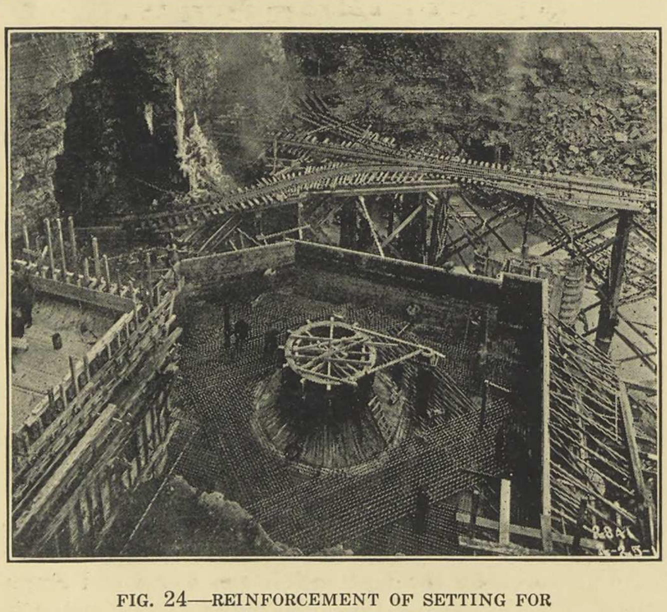


FIG. 24—REINFORCEMENT OF SETTING FOR ALLIS-CHALMERS UNIT

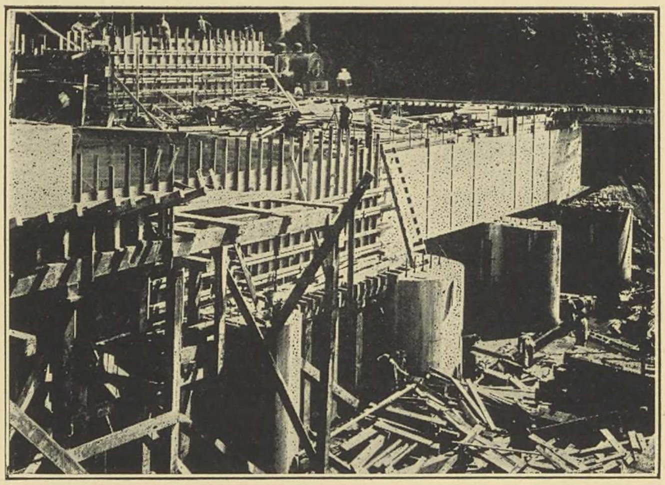


FIG. 25—FOUNDATION SLAB FOR TURBINE SETTING

In the bottom of the forebay and in front of the racks is a long groove running the entire length of the forebay, being 5 ft. deep. It is placed there to act as a stone catcher. As excavation will be carried on in the canal for some time after the completion of the station, loose rocks will be carried down the stream by the swift current and brought into the forebay. As the water in the forebay moves at a velocity of about 1½ ft. per sec. they will drop into this groove and not be carried down the penstock. When this stone catcher becomes filled the loose rocks will be removed by a grab bucket operated from the electric crane in the forebay house.

Ice Skimmer and Run

To prevent ice coming into the forebay an ice skimmer was built in front of the inlets. This consists of removable steel plate sections which extend 9 ft. below the water surface and are hung from the roadway slab above and braced laterally by steel framing to the concrete inlet piers. They will receive considerable pressure if large amounts of ice should be flowing in the basin. It was assumed that very little ice would be carried into the forebay as the velocity of the water in the basin is about 4.5 ft. per sec. and the water going through the ice boom from the basin is 2 ft. per sec. This was very well proved by the experience of last winter.

By the construction of the ice boom system off Port Day in the Niagara River, it was believed that there would be very little trouble from ice in the forebay, but there will always be some ice form in the canal and there will always be the possibility that an ice boom might break and a large quantity come down the canal.

To take care of this a spillway and ice chute has been constructed. The old Station No. 3 had ice gates and an ice run running from the outside of the curve shown on the accompanying plan. This old ice run curved at a right angle and discharged into what had been the abandoned wheelpit of a large flour mill. This pit extended 70 ft. down from the top of the cliff, where the water and ice were discharged on the site of the new power house. It therefore became necessary to build a new ice run running directly from the old spillway gates to the river and passing under the new power house. Its location is shown also on the plan. It is a concrete lined chute 20 ft. wide and 15 ft. deep, inclined at an angle of 60 deg. with a horizontal with a parabolic curve at the top and bottom to connect the horizontal sections with the slope section.

The concrete lining of the chute was intended to be 18 in. thick, but it over ran this as part of the excavation was in shale which disintegrated after being exposed to the air. A concrete roof has been placed upon this chute and will later be covered with rubble stone masonry to look like the natural cliff. The horizontal part of the chute which passes underneath the power house is carried 60 ft. west of the power house so that the water, ice and débris will discharge into deep water of the river.

Details of Turbine Settings

Hydraucone and Center Cone Draft Tubes Used with Vertical Type Unit—Main Foundation Slab is 11 Ft. Thick

BY LOUIS S. BERNSTEIN
Designing engineer Niagara Falls Power Company

THE hydraulic efficiency of the waterwheel unit was the governing feature of the design and for this reason and the fact that the size of the machines are larger and of different type than any in present use, radical departures were made as compared with the existing plants of the company. The fundamental features of the changes are as follows: (1) The vertical shaft type unit was adopted. (2) The usual bent tube type of draft tube was abandoned for the more efficient ones known as the "hydraucone" and the "center cone," respectively.

In plants where the combination of a moderate discharge and the bent-tube type of draft tube exists, the problem of supporting the turbine and generator is comparatively simple, as the loading is usually small and the natural arch of the bent tube acts as the support on one side, and the concrete mass foundation as the support on the other side. It can readily be seen that as

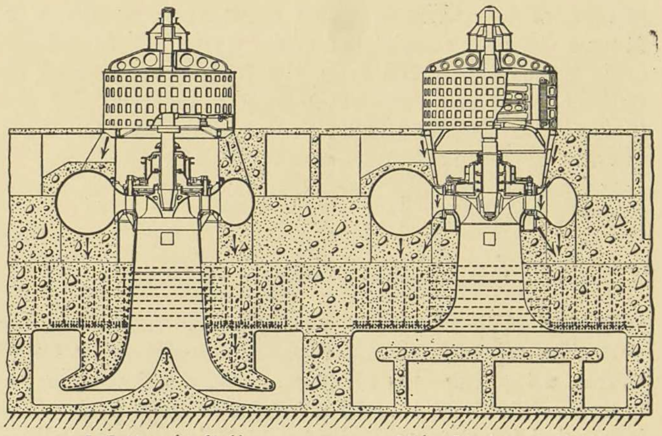


FIG. 26—VERTICAL SECTION THROUGH TWO TURBINE SETTINGS

the unit becomes larger and both the clear span of the tailrace and the load to be supported becomes greater, if the arch type of construction is not available, the problem of supporting the unit becomes more complicated; in special cases, where the turbine and generator are of extreme size and weight, special provision must be made to take care of the vibration of the machine as well as the superimposed loads.

There are two types of units, one being installed by the Allis-Chalmers Co., and the turbine of the other by the I. P. Morris Co. The draft tube of the Allis-Chalmers unit is known as the "Hyrdaucone" while

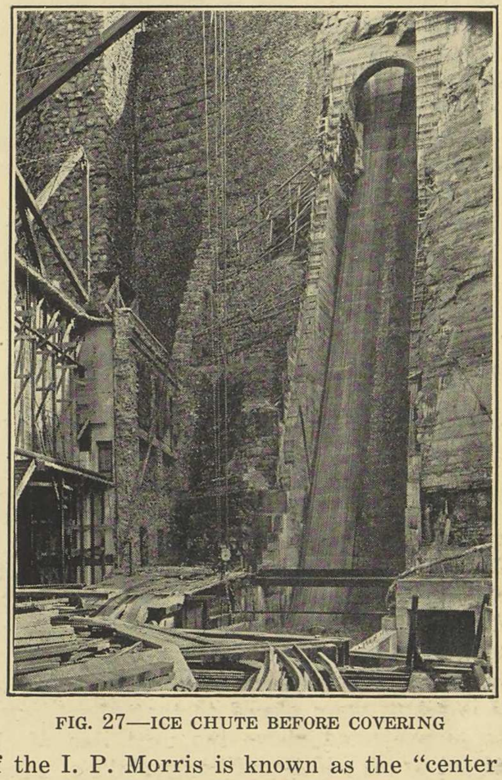


FIG. 27—ICE CHUTE BEFORE COVERING

that of the I. P. Morris is known as the "center cone." In each case tne clearances of the tailrace and the other hydraulic features of the draft tube were determined by the makers of the respective turbines and the hydraulic engineer of the power company. Details of the machines and their appurtenances will appear in a later article.

The draft tube of the Allis-Chalmers unit consists of a horizontal reinforced-concrete plate supported by three reinforced-concrete walls, the entire structure being centered in the tailrace directly under the discharge of the turbine. The draft tube of the I. P. Morris Co. unit consists of heavy flared reinforced-concrete wings suspended from the foundation slab of the unit and a center cone extending up between and centering these wings. The foundations for the units outside of the draft tube are practically the same. A cross section through both units is shown in an accompanying drawing.

CONDITION OF TURBINE LOADING

In the Allis-Chalmers unit the generator is supported by a heavy cast-iron frame called the "pit liner," having a top diameter of 22 ft. 4 in., a diameter at the bottom of 17 ft. 2 in. and a height of 9 ft. 4 in. This is carried by the speed ring which is a circular steel casting that acts as a stationary guide for the water entering the runner. The speed ring in turn is supported by another circular casting called the "discharge ring." This casting rests on the foundation slab, and the concrete inside of this casting is cut out and formed to the shape of the draft tube. The diameter of the opening at the top of the foundation slab is 10 ft. The opening gradually increases in size through the slab and becomes tangent at the bottom. The diameter at the point of tangency is 24 ft. 4 in.

In the I. P. Morris unit the generator is supported by massive concrete piers which rest directly on the heavy cast-iron wheel case. The load is transferred from the wheel case to the foundation slab and the distribution is more favorable than in the other unit. The flared wings of the draft tube are attached to the bottom of the main foundation slab with three rings of reinforcing bars. The opening in the main slab is similar to that of the Allis-Chalmers unit.

The actual weight of one complete unit consisting of one generator and turbine is in excess of 1000 tons. The entire weight from power house floor to the top of the tailrace on the neat inside line of the foundation piers is 5500 tons per unit. It was assumed that this entire load was carried by the main foundation slab. The amount of arch action was impossible to determine owing to the nature of the load concentration of the machine in the vicinity of the opening for the draft tube.

The main foundation slab is 11 ft. thick. It has a clear span of 45 ft. The reinforcing consists of eight bands of steel bars, each band containing twenty-five 1½-in. square bars. In addition to this there are about 450 vertical 1-in. square bars, spaced about 2 ft. centers over the entire area acting like stirrups. It was thought advisable to tie this large mass of concrete together since there is about 1000 yd. of concrete in each slab, and for construction reasons it was decided to pour this slab in two sections. In addition to these vertical bars, limestone plums were placed so that about one-half of the stones projected above the neat line of the first pour to act as an additional horizontal tie. The entire surface was picked, roughened and thoroughly cleaned before the final pour was made.

In the design of the main foundation slab each band was considered acting as a beam and assumed to carry one-eighth of the total load inside the neat line of the foundation piers, the load being considered as uniformly distributed. Based upon this assumption the unit stress in the reinforcing steel is 15,000 lb. per square inch and in the concrete 450 lb. per square inch.

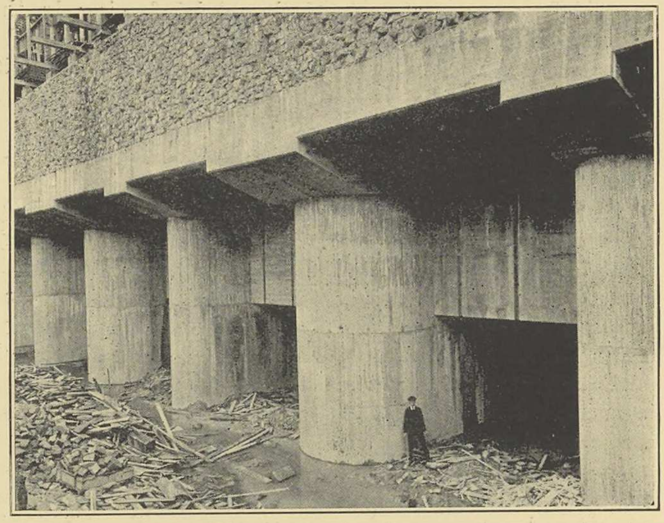


FIG. 28—TAIL RACE EXIT OF EXTENSION TO PLANT NO. 3

The unit shear on the neat line of the foundation piers is 45 lb. per square inch.

The foundation slab is carried by the main power house piers, which are spaced 53 ft. centers, and one smaller center pier. The main piers are 13 ft. thick at the river face of the power house and gradually taper down until they are 8 ft. thick at the center line of the unit. These piers are joined together from this point by a concrete wall 4 ft. thick, against the bedrock, having a radius of 22 ft. 6 in. to the inside face. This makes a horse-shoe shaped tailrace, semi-circular at the rear end and slightly contracting until it reaches the river face of the power house. The piers are rounded off to a radius of half their thickness at the river face of the foundation.

SUPERSTRUCTURE OF POWER HOUSE

The power house, which is located in the gorge, is a building 60 ft. wide inside with a 6-ft. space between the back wall and the cliff, this space being used for cable and hot air passages. It extends 225 ft. upstream from old Station No. 3. The floor of the power house is at El. 365, which is 7 ft. above the highest known water level and is 23 ft. 6 in. above mean water level. The roof is 80 ft. above mean water level.

The operating gallery is 20 ft. wide and extends along the entire west side of the building and is 13 ft. 3 in. above the power house floor, being on a level with the walks leading to the top of the generators and around the Kingsbury bearings,

The east wall of the power house is of concrete and the west wall which faces the river is of rough rubble masonry, being the same as all masonry walls used in the construction of Station No. 3. This type of masonry is used as it harmonizes the best with the existing cliffs.

The weight of the rotating parts of one unit is about 200 tons. Two 100-ton cranes and a lifting beam constituted the crane equipment for the installation of the new plant. The total moving load transverse to the building consists of the live crane load, the weight of the lifting beam and the crane trucks, making a total load of 260 tons. The moving load in the longitudinal direction of the building consists of the weight of the crane bridge in addition to the transverse loading, making a total load of 340 tons. The coefficient of sliding friction between the wheel and the truck was assumed as 0.2. This gave a transverse force of 104,000 lb. and a longitudinal force of 136,000 lb. applied at the top of the crane girder to be taken care of in addition to the regular maximum wheel loading of 76,000 lb.

In the design of the steel work it was assumed that an equal portion of the lateral load would be taken by the top flange of each set of crane girders. The top flange of the crane girders was proportioned for the combined stresses due to the vertical and lateral forces, the span length in each case being the distance between the column centers.

The columns and trusses were designed as a portal fixed at the base. The lateral reaction from the crane girder was assumed to be taken by both the crane column and the truss column. The amount taken by each of these members was determined by the lateral deflection in these members for their particular condition of loading.

The longitudinal force from the crane was assumed to be taken by the crane column, knee braces and the crane girder. In determining the final sections the allowable unit stress in all members that were increased by the lateral or longitudinal forces due to the action of the crane were made 25 per cent greater than the allowable unit stress in the members not affected by this loading.

Factors Determining the Design of Generators

FOR the extension to Station No. 3 the Niagara Falls Power Company placed orders for three generators with three different manufacturers. While about all that was specified was the highest efficiency consistent with other desirable and important characteristics, such as reliability, no restrictions as to the kind of material or weights of parts were placed upon the designer. They are so nearly alike in external appearance, however, that they might well have been built from the same patetrns.

These machines are rated at 32,500 kva., 12,000 volts and due to this size involved interesting problems of design. In the following articles features of design are given by the several designing engines.

Reliability Is Keynote of Generator

Problems Arising in the Selection of Number of Stator Slots, Provision for Insulation and Support of Coils and Thrust Bearing Design Are Discussed

BY F. D. NEWBURY
Westinghouse Electric & Manufacturing Company

THE 32,500-kva. generator built for the Niagara Falls Power Company by the Westinghouse Electric & Manufacturing Company is notable chiefly for its size and for precautions taken in its design and construction to assure reliability and safety in operation. Owing to the rating of the unit (12,000 volts, 1565 amp., 25 cycles and 150 r.p.m.), certain details of design attracted particular attention, namely, the number of slots to use, armature-coil insulation for 12,000 volts, support of coil ends, rotor construction, field-coil insulation, bearing support, lubrication and ventilation. The factors which were taken into consideration in deciding on these details are discussed in the table below.

Number of Armature Slots.—The number of armature slots is a detail that received considerable thought during the design. The choice was between 240 slots and 300 slots, the larger number being finally selected. The advantages of the smaller number of slots are greater ratio of copper to insulation space and a more rigid and stronger coil due to the greater ratio of coil width to coil depth. This is a matter of considerable importance in insulating long coils with mica. The important advantage of the larger number of slots, and the one that decided the selection, is the greater ratio of coil surface to copper loss and the resulting ability to transmit the heat developed in the copper through the insulation with a lower temperature drop. A 0.75-in. slot is narrower than is commonly used in a large 12,000-volt generator. The ratio of *bare* copper width to the *punched* size of the slot is, however, 0.44, which is good considering the high voltage and narrow slot and is possible largely because of the compact machine-wrapped coil insulation.

The importance of a large ratio between armature coil surface and armature copper loss is sometimes overlooked. The problem of dissipating the armature copper loss is very largely a problem of heat-conduction through the armature-coil insulation. In high-voltage 25-cycle generators, having relatively low tooth losses and core temperatures, roughly two-thirds of the temperature rise of the copper is due to the temperature drop through the insulation and only one-third is due to the temperature rise of the armature teeth above the cooling air. It follows, therefore, that the factors affecting the dissipation of heat by ventilation are relatively only half as important as factors affecting the conduction of heat through the insulation. To illustrate: Assume a total armature copper temperature rise of 60 deg., then 20 or 25 deg. would be the tem-

PRINCIPAL DIMENSIONS AND WEIGHTS OF 32,500-KVA., 12,000-VOLT, THREE-PHASE, 25-CYCLE, 150-R.P.M. WESTINGHOUSE GENERATOR

Stator	
Outside diameter of core	228 in.
Inside diameter of core	197 in.
Core width (including 30—⅜ in air ducts)	65 in.
Number armature slots	300
Dimensions of slots	.75 x 4.75 (over all)
Coils located in slots	1 and 14
Armature winding	Y connected — 4 parallel circuits
Size of conductor strands	.204 x .258 (mica taped) .129 x .274 (bare)
Arrangement of conductors	See illustration
Turns per phase in series	75
Development length — one turn	257 in.
Rotor	
Outside diameter	196 in.
Single air gap	0.5 in.
Pole face	21 in. x 65 in.
Pole body	15 in. x 65 in.
Radial height of pole	12⅛ in.
Field winding	42½ turns per pole .203 x 2.25 bare strap
Developed length —one turn	167 in.
Amperes excitation no. load 12,000 volts	323
Amperes excitation 1,565 amp. 12,000 volts, 80 per cent P.F.	632
Weights	
Total weight of generator	650,000 pounds
Total load on thrust bearing	478,000 pounds
Weight of generator rotor with shaft	318,000 pounds
Weight of one pole and coil	4,800 pounds
Net weight armature punchings	133,000 pounds
Weight top supporting bracket	58,000 pounds
Total weight copper	33,000 pounds
Flywheel effect rotor (FR^2)	11,500,000
Shaft and bearings	
Outside diameter thrust bearing	49 in.
Total bearing surface—thrust bearing	1,350 in.
Dimensions upper guide bearing	25 in. diameter 42 in. length
Maximum diameter shaft	28 in.
Outside diameter shaft flange	45 in.

perature rise of the armature teeth above the cooling air and the balance would be the temperature drop through the coil insulation. If by some means, such as doubling the quantity of cooling air or doubling the surface exposed to the air, the heat dissipation by convection could be doubled, the copper temperature rise would be reduced by 10 or 12 deg. If, on the other hand, the drop through the insulation could be cut in half by increasing the coil surface or by decreasing the thickness of insulation, then the copper temperature rise would be reduced by approximately 20 deg. This discussion is based on the assumption of long cores (as in the present case), in which the ventilation of the coil ends has very little influence on the temperature of the copper in the center of the core.

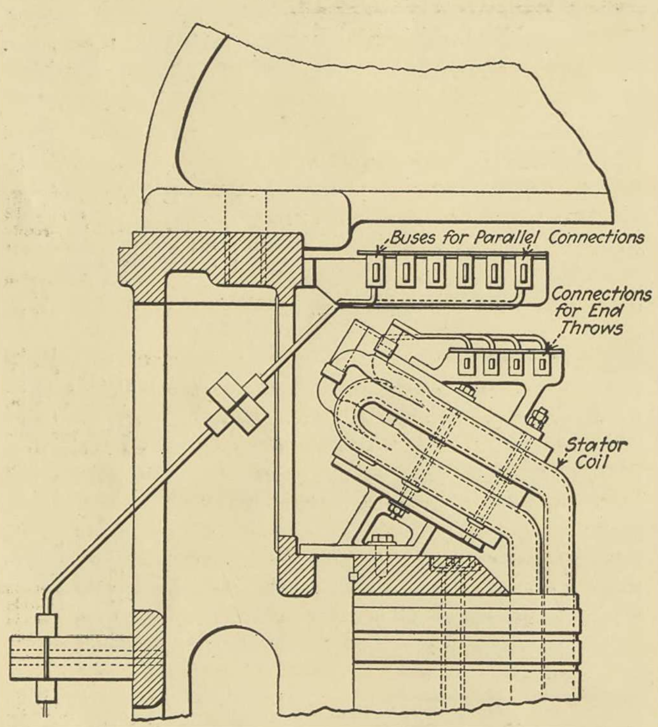
Armature Coil Insulation.—One of the distinctive features of this generator is the heat-resisting qualities of the insulation. Mica is used as the insulating material beginning with the bare copper conductor. This type of insulation has been developed particularly for the larger 60-cycle steam-turbine driven generators, in which it is impossible to design the windings so that the copper temperature is within the safe limit for ordinary vegetable fiber insulation. This mica insulation is regularly guaranteed for operation up to a temperature of 150 deg., and it has been successfully tested up to 300 and 400 deg. for short periods. Its use in the present instance was not dictated by operating temperatures, as these are well below 100 deg. (even allowing for inevitable differences between measured temperatures and the actual copper temperature), but it was used in accordance with the builders' policy to use the best materials and constructions available and thereby provide the maximum operating factors of safety.

The detail construction of the armature coil will be understood by reference to accompanying illustrations. Each coil consists of three active conductors and each conductor is built up of four strands or wires. The single conductor is split up in this way in order to reduce eddy currents. The winding is also connected in several parallel circuits for this same reason, as well as for the additional purpose of obtaining the desired number of conductors.

The coils are formed of bare copper ribbon. Two sizes of strap are used, so that complete strand insulation is provided by taping the two larger ribbons with mica tape. Each group of four strands, forming an active conductor, is insulated with mica tape and the insulation between conductors is reinforced by strips of hard-baked mica. The three conductors of one coil are then assembled and the complete coil bound with thin cotton tape, after which the straight parts to be embedded in the slots are brushed with bakelite, and these parts are pressed to the required dimensions in a steam press. This solidifies the bakelite and makes the straight parts of the coil sufficiently strong and rigid to withstand the twisting forces of the wrapping machine. The ends of the coils, which must be relatively flexible, are impregnated in a vacuum tank with hydrolene.

After this impregnation, the mica wrapper is applied to the straight parts of the coil. The wrapper is first applied to the coil in sheet form by hand, being drawn around the coil rather loosely. It is then placed in a wrapping machine equipped with electrically heated ironing plates, which revolve around the coil, heating and softening the bond. This permits the different turns of the wrapper to slide, one on the other, and with the heavy pressure exerted by the ironing plates produces an extremely solid and compact insulating wall. This machine-wrapping process has two important advantages due to the compactness with which the insulation is applied.

The relatively poor heat conductivity of all coil-insulating materials is due to the minute layers of air between the layers of insulating material. Consequently, the more tightly the insulation can be wrapped



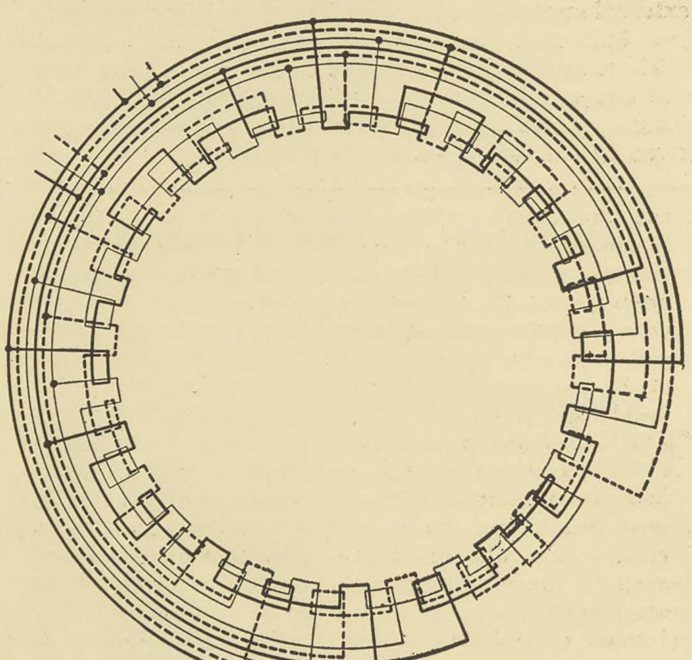


FIG. 29—SECTION THROUGH PORTION OF STATOR SHOWING SUPPORT OF END COILS. FIG. 30—SIMPLIFIED ARMATURE WINDING

As seen in Fig. 30, parallel grouping of coils is accomplished through buses shown by the six outside circular arcs. Six leads are taken off (both ends of three phases) and the star and neutral connection made outside of the machine.

and the more completely these air pockets are eliminated the better will be the heat conductivity of the insulating wall. The total thickness of the insulating wall is also reduced, and thus relatively more space is available for the active materials.

The curved ends of the armature coils are insulated with a number of overlapping layers of varnish-treated cloth, each layer being brushed with insulating varnish. Cloth insulation is best suited for this part of the coil on account of the curved form of the coil and the required flexibility while placing the coils in the slots. The temperature of the coil ends is low compared to that at the center of the core, so that cloth insulation can be used with a liberal factor of safety notwithstanding its low safe temperature.

Mica insulation requires no protection against the disintegrating effects of static discharge or corona, such as, for example, the grounded metallic sheath that is sometimes used when varnished cloth or paper is used in high-voltage generators for the slot insulation. Many years' experience with mica insulation has proved beyond question that this material is unaffected by corona at the voltage gradients ordinarily employed. At the same time static discharge is more commonly present—evidenced by ozone—in mica-insulated generators than in those employing vegetable fiber insulation. This is due, of course, to the higher voltage gradients that are possible with mica and to the higher specific inductive capacity of this material.

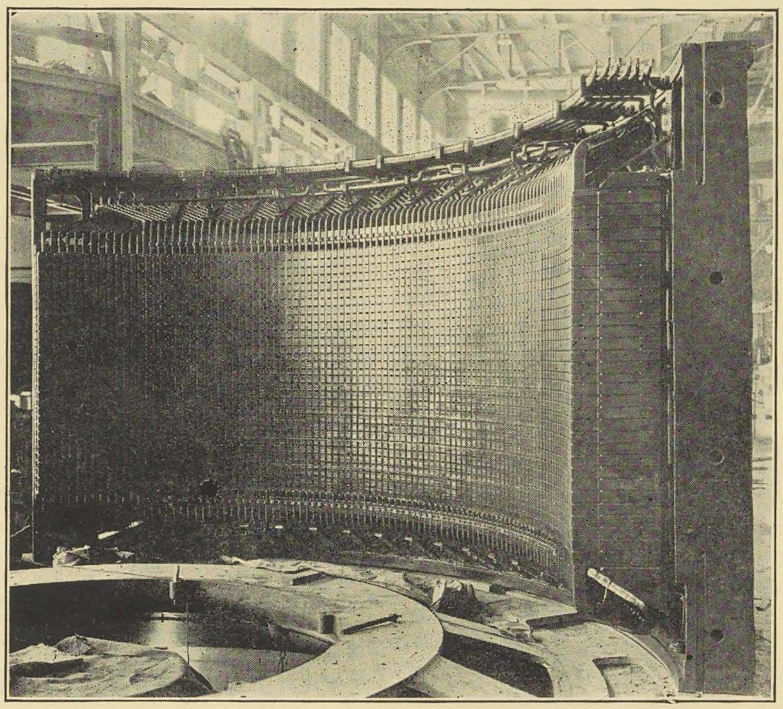


FIG. 31—SECTION OF COMPLETED ARMATURE IN PLACE

These windings are connected in parallel with three similar sections by heavy buses shown at the top. Fig. 30 shows the armature winding scheme.

Armature Coil Supports.—The coil ends are so shaped that the conical surface formed by the complete winding forms an angle of 60 deg. with the armature air gap surface. This is done to provide room for the coil bracing and to decrease the axial length of the coil ends. Liberal ventilating spaces are provided between coil ends, which are also necessary for the bronze bolts of the coil supports. This type of coil support has been developed for the largest steam-turbine generators and provides an unusually large factor of safety when applied to a 20-pole water-wheel generator. This is another instance of using the best available construction and providing a very liberal factor of safety. The straight parts of the coils immediately outside the core are supported in a circumferential direction, by carefully fitted wood blocks.

Rotor Construction.—The rotating part is guaranteed to operate safely at 100 per cent overspeed and at this speed the surface velocity is 15,400 feet per minute. This is a relatively low angular velocity—less than one-sixth that of large 60-cycle turbo-generators—so that the stress conditions are relatively easy and can be taken care of by any one of a number of well-established constructions. The spider hub and arms form a single casting. Each arm carries two small dovetail slots for spacing the punchings in building up the rim, but these small dovetails are not depended on to carry any of the radial load imposed by the rim, poles and field coils.

Field Coils.—The field coils are formed of bare strap, wound on edge and insulated between turns with asbestos. This is applied with shellac, and during the construction of the coil the coil is heated in an open gas flame to completely burn out the shellac. The insulation between the copper and pole is formed of molded mica and asbestos, and micarta washers are used at the top and bottom of the coil for mechanical protection. The field coil insulation, as in the case of the armature coil insulation, is guaranteed to withstand safely a total temperature of 150 deg. even though the operating temperature is well below this figure.

Thrust Bearing.—The thrust bearing is of the well-known Kingsbury type. There are six babbitted shoes supported on hardened jack-screws, which are raised or lowered as necessary to adjust the shoes to take equal shares of the load. The use of these adjusting screws also permits any shoe to be removed for inspection without lifting the entire rotor. Occasional inspection is desirable because it may disclose, by the scoured appearance of the babbitt, the presence of dirt in the oil or other objectionable conditions and permit the correction of the difficulty before serious damage to the service has occurred. When filled with oil to the running level the bearing housing holds 270 gal.

Lubrication.—There are but two points of lubrication in the generator, the thrust bearing and the upper guide bearing. Both of these bearings are fed independently from a central station oiling system and drain independently to the station reservoir. The oil drainage from the guide bearing passes through a hole in the spider hub to a stationary oil pan below. There is an instrument board, located on the thrust bearing housing and facing the passageway to the station operating gallery, containing indicating dials for oil meters in the thrust-bearing line and in the guide-bearing supply line and indicating dials for thermometers in both thrust and guide bearings.

Ventilation.—The generator rotor has inclined fan blades mounted on each side of the spider rim. Each end of the armature is enclosed so that the fans deliver

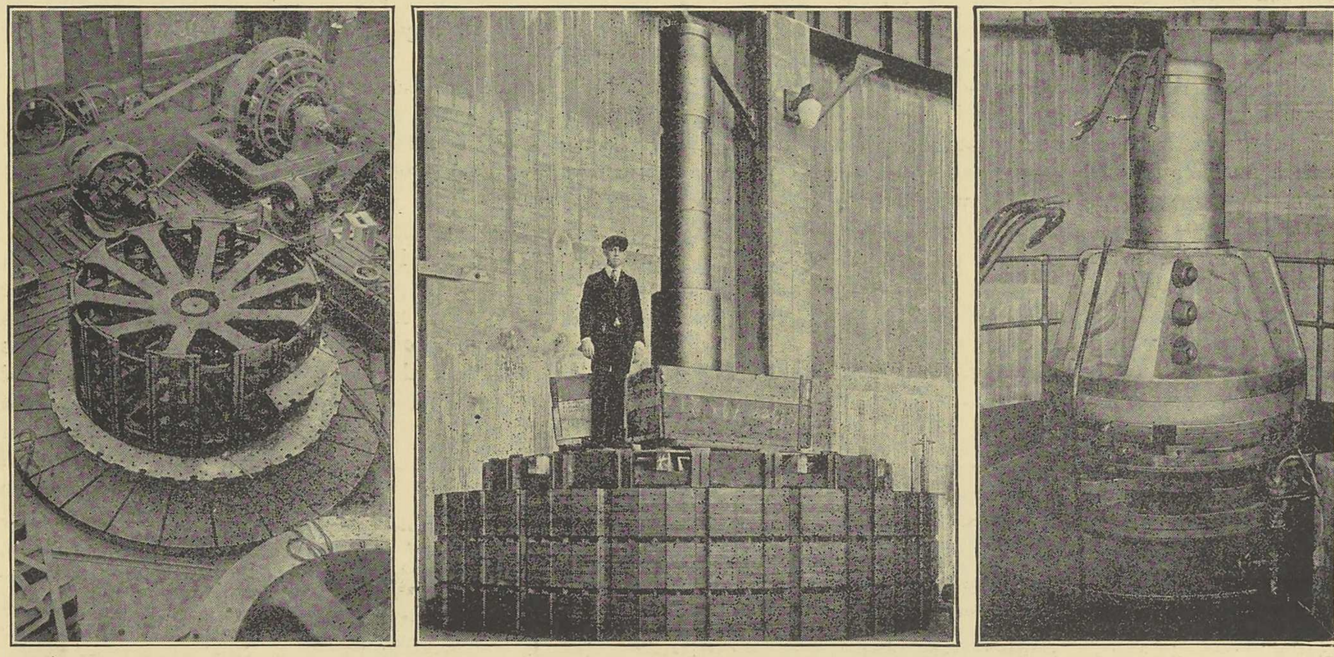


FIG. 32—ROTOR SPIDER AT FACTORY AND BEING ASSEMBLED WITH RIM. THRUST BEARING DURING ASSEMBLY AT RIGHT

air into closed pressure chambers, from which air is forced into the air gap and between the field coils and through radial ducts in the armature core. Air enters the generator from both top and bottom. The generator frame is surrounded by a circular sheet steel casing in which all of the warm air from the generator is collected and discharged outdoors.

There are twenty thermocouples located between coil sides in the armature slots and six couples on the outside of the armature coil ends. These latter couples were installed to duplicate mercury thermometer measurements as ordinarily taken on smaller open-type generators and for comparative purposes only. The couples built in the core are well protected from possible air currents where the armature vent ducts cross the slots and should give indications reasonably close to the actual temperature of the copper inside the insulation. At 28,500 kw., 90 per cent power factor and 13,000 volts the highest reading thermocouple within the core gave a rise of 56 deg. C. and the highest reading couple on the outside of the coil ends showed a rise of only 23 deg. C. This, as stated before, is equivalent to the thermometer measurement formerly used and for which a temperature guarantee of 50 deg. rise was standard practice.

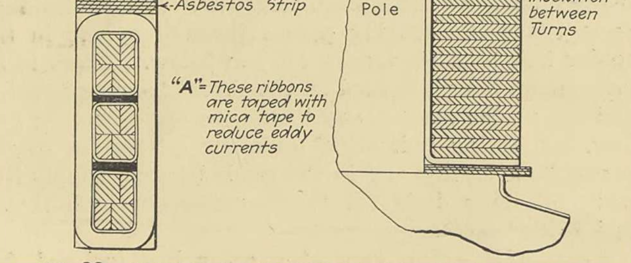


FIG. 33—SECTION OF ARMATURE SLOT AND FIELD COIL
Armature strands are of different size and complete insulation is provided when only two strands are insulated.

Operating Experience Proves Correctness of Design of 32,500-Kva. Generator

BY R. B. WILLIAMSON
Engineer in charge of Alternating-Current design, Allis-Chalmers Manufacturing Company

THE 32,500-kva. generating unit built for the Niagara Falls Power Company by the Allis-Chalmers Manufacturing Company is mounted directly above a 37,500-hp. turbine, the two forming a close-coupled unit with a relatively short distance between the two machines. The generator of this unit was described by the writer in the ELECTRICAL WORLD, Aug. 30, 1919, before it was put into service, but further information is now available as a result of several months of operation.

The shaft is short and stiff and the combined unit has but two guide bearings, one at the top of the generator immediately below the thrust bearing and the other directly above the waterwheel runner. To carry the generator a large cast-iron barrel of heavy-ribbed design is bolted to the cast-steel speed ring of the turbine, thereby transmitting the weight of the generator through the barrel to the speed ring and foundation below the wheel.

With these large vertical units it is necessary to provide brakes for bringing the machine to rest and for holding it in case of leakage through the wheel. In this instance the brakes are operated by air pressure and engage the lower surface of the field spider rim. On account of the large size of the generator it was considered advisable to stack the laminations and put the stator coils in place in the field after the stator yoke had been set on the pit liner connecting the generator and turbine as shown in the illustration above.

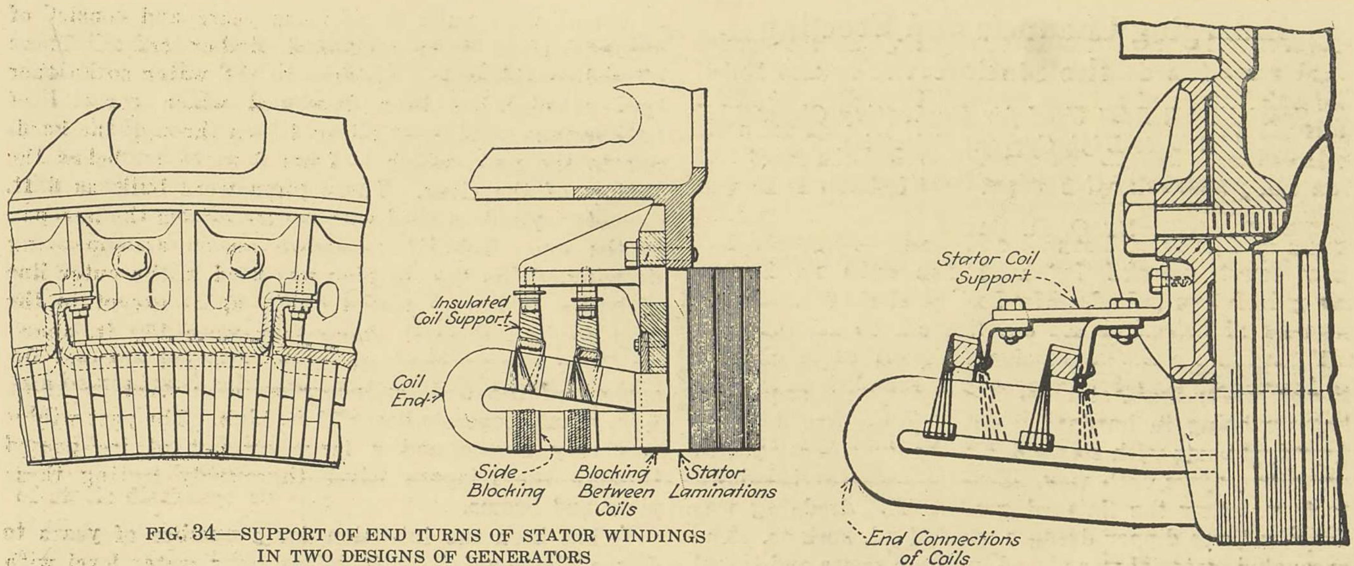


FIG. 34—SUPPORT OF END TURNS OF STATOR WINDINGS IN TWO DESIGNS OF GENERATORS

The temperature rise guaranteed on the generator was 55 deg. C. as indicated by resistance coils placed in the windings between the upper and lower coils in the middle of the stator core. Continuous operation at full load has shown the rise as thus indicated to be well within the allowable limit. The winding is equipped with twenty temperature indicating coils, and the rise as indicated by them is quite uniform throughout the machine. Measurements of the temperature rise and quantity of oil circulated through the thrust-bearing casing indicate that the friction loss in the bearing does not exceed 25 hp. or 0.066 per cent of the rated output.

In the present design the coils are securely blocked just where they project beyond the core to protect them against any side motion and consequent danger of breaking the insulation at the ends of the slot. They are also lashed to the insulated supports, as indicated at the right in the accompanying sketch. These supports are made in sections and are bolted to projecting brackets cast on the stator end heads.

As this generator requires approximately 80,000 cu.ft. (2,240 cu.m.) of air per minute for carrying off the heat, the arrangements for handling the air required careful consideration. Air is taken in at the top and also from the pit underneath and, after passing over the windings and through the stator yoke, it flows through ducts and is forced out of the station by means of auxiliary fans. This method was decided upon after careful consideration and conferences between the Niagara Falls Company engineers and the designers.

Design of 32,500-Kva. Generator Is Conservative—*

BY W. J. FOSTER
Designing engineer, General Electric Company

CONSERVATISM has characterized practically every feature of the design of the generator built by the General Electric Company. The mechanical stresses allowed in the various parts, such as bearings, spider and rotor, are in many cases no higher than is sometimes allowed when using cast iron, whereas the best steel is being used. Because of the high efficiency that has been striven for relatively small losses occur and the insulation is not required to withstand abnormal temperatures. The guarantee to the customer is a 100-deg. C. machine at the rated output—32,500 kva. This is 5 deg. more conservative than the standard of the American Institute of Electrical Engineers for class A, or low-temperature, insulation, whereas the insulation that has been used in the armature for both turn and external insulation is class B. This insulation, according to A. I. E. E. standard, is suitable for 125 deg.

In order to produce a simple and mechanically strong rotor the rotor spider was constructed of six wheels, each wheel a single casting of steel. The upper end of the shaft is machined for a thrust collar which takes the entire weight of rotating parts and for a guide bearing which is immediately below the thrust bearing. Only one other guide bearing is provided, and that is on the waterwheel.

The reactance of the generator is approximately 20 per cent, which permits the stator winding to be supported mechanically with unusually large factors of safety against the stresses produced by instantaneous short circuits. The projecting ends of the winding at both top and bottom rest back against two solid steel rings that are carried by brackets attached to the heads of the stator. These rings are heavily insulated to form a seat for the coils. The individual coils are laced to supporting bands by strong linen cord specially treated. The individual coils also have spacing blocks laced to their sides at short intervals, of such thickness as to make the completed winding perfectly ring-bound.

*Covered more completely in May 31, 1919 ELECTRICAL WORLD.

Enlarging Channels and Erecting the Station

Special Drill Boat Used for Excavating Channel Due to High Current Velocities.

Details of Cofferdam Construction.

BY O. D. DALES

Construction engineer Niagara Falls Power Company, Niagara Falls, N. Y.

THE excavation of the 20-ft. channel from the head of the canal out into the Niagara River was through limestone for the first 1,000 ft. out from the shore, the balance being in hardpan. The drilling was done by four drill boats with steam drills, the holes being placed on 4-ft. centers each way. Drilling was carried down to 3 ft. below the finished grade. The dredging was done by three dipper dredges with 6½-yd. buckets. The excavated material was placed in dump scows and towed out into the river just above the upper rapids, this class of excavation being similar to most dredging operations in large rivers. Disposing of the excavated material was rather difficult on account of the location of the dumping ground. Extreme caution was exercised by the contractor, but in spite of this one dump scow broke its two tow lines and floated down the Canadian channel to below the upper cascade rapids where it went aground on some rocks about 800 ft. from the Canadian shore. The two men on board were removed by the Fort Niagara life-saving crew by means of shooting a line out to the scow and bringing them ashore in the breeches buoy.

Most of the piers for supporting the two inner lines of booms were built in previous years and consist of concrete piers upon rock-filled timber cribs. These offered considerable resistance to the water so another type of pier has been developed which consists of Lackawanna steel sheet piling driven through the hardpan to the rock, which is from 6 to 15 ft. below the bottom of the river. These piers were built as 6 ft. diameter cylinders filled with concrete from the hardpan to the top. Details are shown on an accompanying drawing. This type of pier was used in the outer line of booms and were placed 50 ft. apart except in the deep dredged channel where they were 150 ft. apart. As there was no hardpan in the dredged channel the bottom of the 6-ft. cylinders were encased in 19-ft. 6-in. square concrete bases 12 ft. high. The past winter was very severe and a large amount of ice passed through the Niagara River thoroughly testing these piers and booms.

It has been the intention for a number of years to deepen the canal to 20 ft. below mean water level with a cross-section approaching as nearly as possible the typical section shown on the drawing herewith. Excavation had been carried on in the canal for a great number of years and up to 1912 had been excavated on the right-hand half, looking downstream, down to 20 ft. for nearly the entire length of the canal. The left-hand side of the canal was left at 14 ft. deep, while under the bridges it was approximately 14 ft. deep on both sides.

In order to have sufficient water available for the operation of the new plant along with the old plants it was necessary to excavate and clean up the canal to a depth of 20 ft. for the entire width approaching the typical section shown on the drawing. The excava-

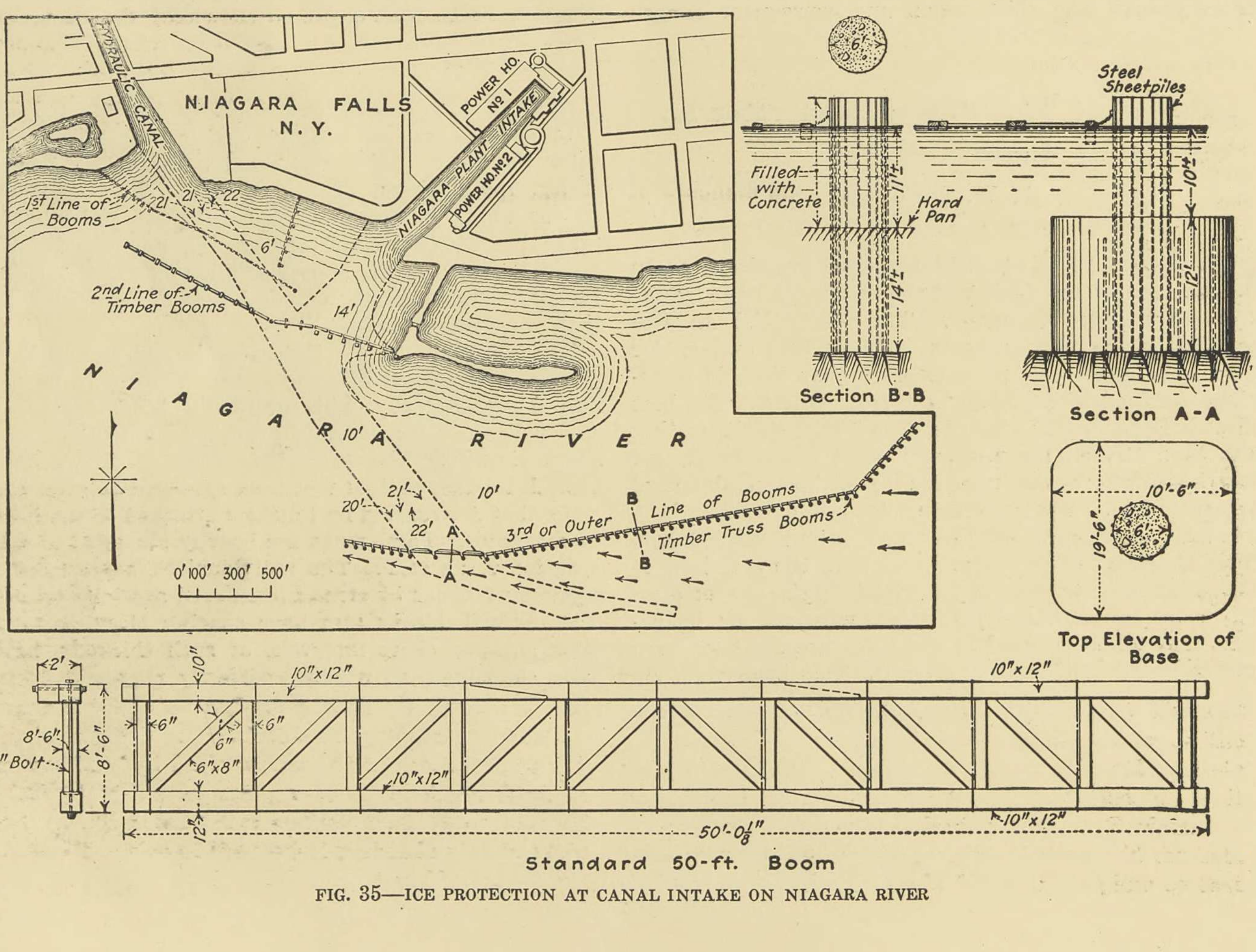


FIG. 35—ICE PROTECTION AT CANAL INTAKE ON NIAGARA RIVER

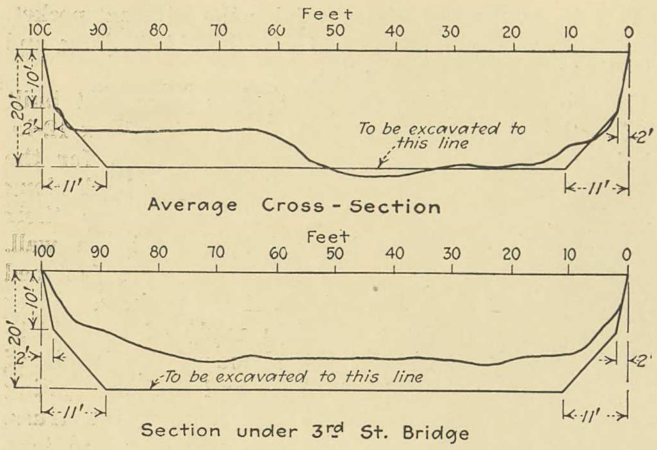


FIG. 36—TYPICAL CANAL CROSS-SECTIONS

tion in the canal was a much more difficult task than that of the river. It was all in hard tough limestone, and the mean velocity of the water was 6 ft. per sec. which gave a surface velocity of 10 ft. per sec. when dredges and scows were in place. Eight bridges span the canal which vary from 6 to 15 ft. above the water surface. The drilling and blasting in such a severe current presented many difficulties, but was accomplished from a drill boat which was developed for this work.

Canal Drill Boats

The canal drill boat is equipped with five tripod drills operated by a crew of 12 to 15 men. Each drill has one runner and helper. The drill-boat bow is divided into 12 spaces 4 ft. apart and the boat moves back on ranges 4 ft. apart, making the spacing of the holes 4 x 4 ft. and they are drilled 3 ft. below finished grade.

The drill steel is 1¼ in. diameter and from 20 to 26 ft. long, depending on the depth of the water, with 1½- to 2½-in. bits. The steel drill rods are protected from the current by a main guide barrel of different lengths so as to keep it at least 3 to 4 ft. above the rock. The main guide barrel is 6 in. in diameter and has a 3-in. slit opening from the top to the bottom so that the steel drill rods may be pulled into place. At the bottom of this main guide barrel is a 1½-in. ring band to which a cable with a chain fastening is attached to the upstream end of the boat so as to keep the main guide barrel in a vertical position against the strong current. In order to protect the drill rods down to the top of the rock, a 4-in. diameter pipe and a 2¾-in. diameter pipe, one 6 ft. long and the other, or bottom piece, 5 ft. long, are made to telescope one another. This telescopic pipe is inserted into the main guide barrel and dropped to the bottom by a chain. There is a ½-in. round rivet stopper about 3 in. long which projects out from the side of the telescopic barrel about 6 in. down from the top and as the stopper slides down the slit in the main guide barrel it is stopped by the 1½-in. round cable band at the bottom of the main guide barrel which holds the telescopic barrel in place and which is lengthened or shortened by the telescopic action and weight of the pipe.

The drill rods were put into place by hand. They are first run about half-way out from the end of the boat and pulled back into the main guide barrel through the slit opening by two men and dropped to the top of the rock. As each two feet are drilled it is replaced by a longer drill rod.

In blasting a 2-in. tin tube 20 ft. long is run down to the top of the hole through the guide pipe which keeps it from bending or breaking. The sticks of dynamite are put down the tube by a sectional lowering stick, the exploder stick being in the center of the charge which has the two wires attached and extend to the boat up the tube. Before the charge is fired the telescopic barrel is pulled up into the main guide barrel by the chain and let stand, also the tin tube is removed. The charge is set off by a battery and one hole is fired at a time. The kind of explosives used is 60 per cent Dupont and averages about 1 to 1½ lb. per uc. yd.

The ordinary 1½-yd. dipper dredge was used for dredging between the bridges. The dredging under the bridges was accomplished by two dipper dredges with extremely low cranes, one having a ¾-yd. and the other a 2-yd. dipper. These dredges were developed particularly for this work on the canal and have given very satisfactory results. One is shown in operation in one of the views.

The rock excavated from the canal was placed in steel skip boxes on board scows and floated down the canal under the control of a strong tug to the crusher plant at the canal basin where the rock was unloaded by derricks and crushed. From this point the rock was shipped by train and truck.

The drill boat and dredges built for this canal work were developed by R. R. Coddington, General Superintendent, from his many years' experience on this class of excavation. The contractor for the excavation in the river and canal is the Great Lakes Dredge & Dock Co.

Basin Excavation

The old canal basin which connected the canal with the inlet to Station No. 3 was 70 ft. wide and approximately 18 ft. deep. As the water for Station No. 3 Extension is taken from this basin, it was necessary to increase the carrying capacity of this basin which was done by increasing the width by excavating on the east side to a width of 117 ft. at the upstream end of the forebay inlet and gradually narrowing down to the old width of 70 ft. near the inlet to old Station No. 3 A curve of 143 ft. radius tangent to the north line of the canal and to this new basin line has made a very good entrance to the basin. With this enlargement of the basin the mean velocity of the water will be 4.5 ft. per second.

The top of the limestone rock lies about 8 ft. below the earth surface and about 2 ft. above the water surface in the basin. The earth was excavated with a

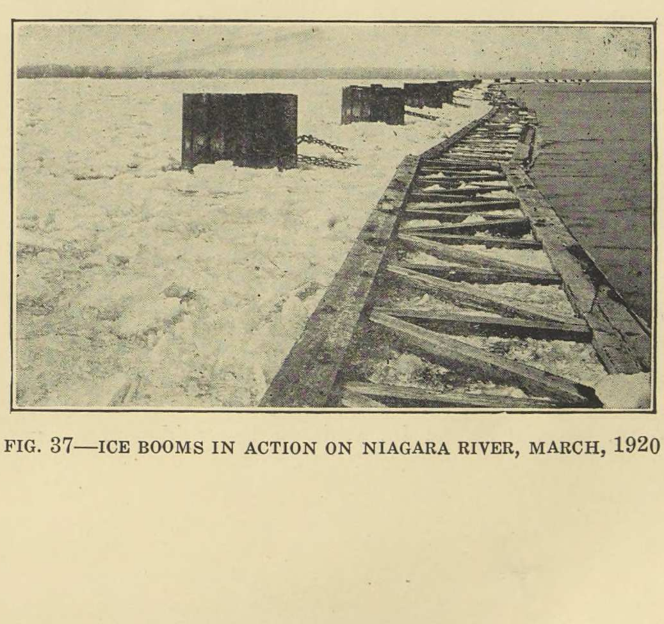


FIG. 37—ICE BOOMS IN ACTION ON NIAGARA RIVER, MARCH, 1920

¾-yd. steam shovel. The rock was drilled and blasted in the dry down to about 2 ft. below the water surface by leaving a narrow ridge of solid rock as a cofferdam. The blasted rock was removed into dump wagons by the ¾-yd. steam shovel.

The next 11 to 13 ft. down was drilled and blasted in the dry and removed with a dipper dredge. The drilling was done with tripod drills, holes being placed about 4 ft. apart each way and along the side it was close drilled. These holes were 6 to 8 in. apart. It has been found that this close drilling in this class of rock gives a comparatively smooth wall for the side of the cut. In the excavation above water 0.8 lb. of 60 per cent dynamite per yard was used.

The lower 9 ft. of excavation for the basin enlargement was drilled and blasted from the drill boat and removed by the dipper dredge along with the deepening of the rest of the basin and in the same manner as the canal excavation.

Much of this basin enlargement was done in the summer and fall of 1918 when it was imperative on account of the war to keep all the old power plants running to their utmost capacity. The blasting up of the bottom of the basin, the ridge formed in front of the dipper dredge and the dredge with scow restricted the cross-sectional area so as to increase the velocity of the water very much. These conditions are shown in the view on p. 29, which was taken Oct. 19, 1918. The work was done in strips the length of the basin and sufficiently wide for the convenient operation of the dredge. Each strip was completed through before beginning another so as to reduce the cross-section as little as possible.

The forebay was built in rather cramped quarters, being separated from the basin by the basin road and between two large flour mills on the north and south, while on the west were busy switchtracks.

The old west wall of the canal basin, which is shown on p. 29, is built of concrete upon limestone. The top of the rock is at about water level. Under the roadway the inlets to the forebay have been built.

In the construction of the forebay this west wall with a wider strip of rock under it was at first used as a natural cofferdam for the excavation. As soon as the basin had been widened and deepened enough by dredging to allow a cofferdam to be built in it and also permit about 7000 sec.-ft. of water to pass to old Station No. 3, a cofferdam was built. It was quite important that this cofferdam should restrict the flow as little as possible. With this in mind a narrow cofferdam was built of Lackawanna 12¾ x ⅜-in. straight web steel sheet piling in water varying in depth from 16 to 24 ft. The cofferdam consisted of 18 oval-shaped pockets. The size of the typical pocket in plan is 14 ft. 4 in. long, 9 ft. 10 in. wide at the mid-section, and 6 ft. 5 in. at the end where it joins the adjacent pocket. The outside row is composed of piles 24 ft. long and the inside row of 20-ft. piles.

In the construction, timber trusses were first built in lengths 28 ft. long and 8 ft. deep, using 12 x 12-in. timbers for the chord members and 8 x 8's for the diagonal members. These were built on the bank along side of the basin, launched, and floated into their place which was along the old concrete basin wall. Upon the cofferdam side of the truss were fastened timbers shaped to fit the outside of the pockets. After the truss was in place templets made of two thicknesses of 2-in. plank and the shape of the inside of the pocket were floated into place and the sheet piling placed around these templets and against the truss. Work was begun at the upstream end so as to take advantage of the current. As soon as the piling for one pocket was placed they were driven with a light piledriver so as to drive them through any loose rock which might be on the bottom of the basin and cause them to fit as closely as possible to the solid rock. After this a diver went down into the pocket and closed up any openings that were found between the piling and the rock, using bags filled with concrete. Good rich concrete was then poured in the bottom of the pocket for a depth of about 2 to 3 ft. so as to properly seal the bottom and thoroughly fasten the cofferdam to the rock. The pocket was then filled up to the top with ordinary gravel, the pressure of this gravel causing the pockets to bulge slightly and completely tightening the joints. This made a very narrow cofferdam but it was thoroughly fastened to the rock at the bottom by concrete and at the top supported by two stiff wooden trusses.

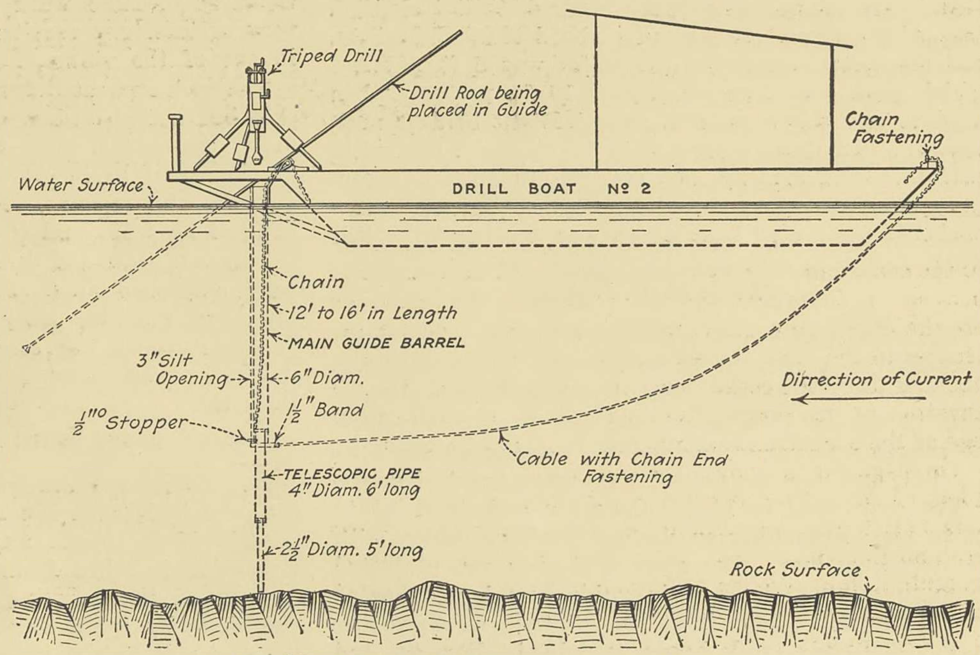


FIG. 38—DRILL BOAT USED IN CANAL EXCAVATION

In excavating the rock back of this old basin wall as much solid rock was left as possible between the piers to act as pilasters for supporting the old concrete wall which was receiving the load thrust upon it through the trusses from the top of the cofferdam.

As soon as the piers were completed the old concrete wall was removed directly in front of the piers so that

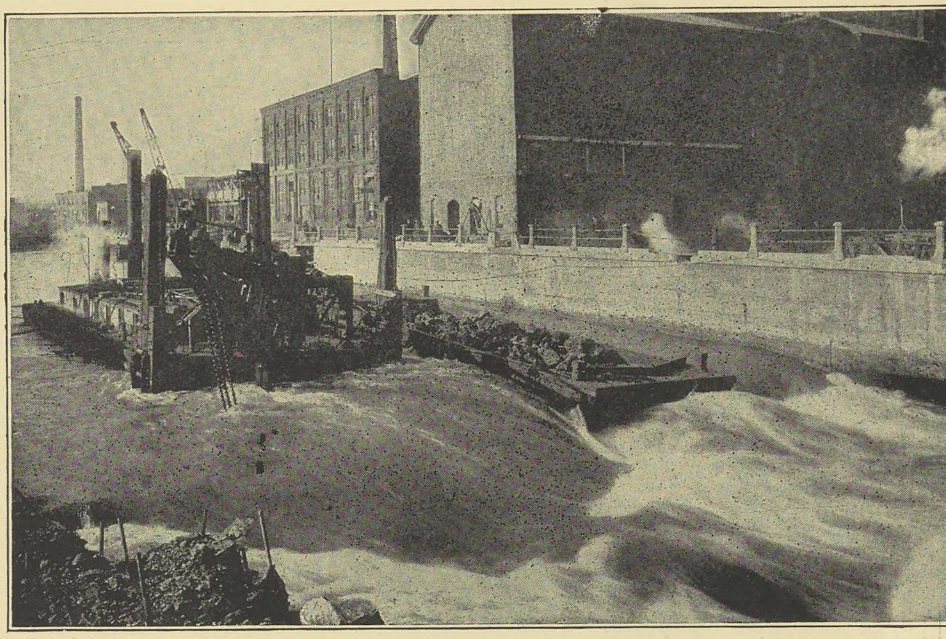


FIG. 39—DREDGING IN A STIFF CURRENT IN THE NIAGARA HYDRAULIC CANAL

timber struts could be placed between the trusses and the piers, thereby transferring the pressure of the top of the cofferdam from the old wall to the new piers. The old wall and the rock between the piers was then blasted and removed.

Excavation back of the cofferdam was carried down to a depth of about 6 to 8 ft. below the bottom of the cofferdam and within an average of about 2 ft. of the inside line of the cofferdam, and in a few places the rock broke back of this inside line. The concrete seal which had been placed in the bottom of the pockets could then be seen quite plainly in such places and showed that a good bond with the rock bottom had been made. As the excavation progressed downward and closer to the cofferdam, extra struts of 12 x 12-in. timbers were placed from the piers to the cofferdam. The view on page 31, which was taken back of the cofferdam, shows the piling of the cofferdam on the right, the piers on the left with the timber trusses above, and the excavation carried up to within about 2 ft. of the cofferdam. At the time when the excavation of the forebay was completed the entire leakage of the cofferdam and rock did not exceed 4 sec.-ft.

On page 30 is shown the completed cofferdam. As some of the piling drove into the bottom farther than was anticipated on account of there being more loose rock on the bottom than was expected, it was necessary to build a light wooden cofferdam along the top in order to take care of any extreme high water.

It was necessary to locate the power house as close to the cliff as possible in order to get the foundations and tailraces on solid rock. The top of the cliff here is about 218 ft. above the water level in the gorge. Extending upward about 100 ft. from the water surface is a talus slope which consists of a layer of about ten feet of loose rocks which had fallen from the cliff.

Excavation was begun at the toe of the slope using a ¾-yd. steam shovel, the loose rock being washed down to the shovel with a hydraulic giant. This hydraulic giant had a 4-in. nozzle and the water was supplied to it by a 10-in. pipe line carried from three of the 9-ft. penstocks in old Station No. 3. This gave a working head of about 180 ft. at the nozzle. As soon as sufficient area had been cleaned off with the hydraulic giant, drilling and blasting of the solid rock was begun. Excavation of the solid rock was carried down to about 4 ft. above mean water level. Then a concrete cofferdam was built on solid rock the length of the proposed power house and about 60 ft. west of the west wall of power house. Excavation was then carried down to 23 ft. below mean water level. The excavation above El. 370 consisted of shale and limestone, from this to the water surface alternate layers of Medina sandstone and red shale, and below the water level was solid Medina sandstone.

As soon as the excavation was completed the concrete foundations for the turbines were poured. The mixing plant was located at the top of the cliff. The gravel was brought in on cars and unloaded onto a belt conveyor which carried the gravel to a storage pile. It was then conveyed from the storage pile to hoppers over the mixers by a clamshell bucket operated from a derrick. The mixed concrete was conveyed through flexible sheet iron, elephant trunk, chutes suspended in cables extending from the top of the cliff to the bottom.

The piers and heavy reinforced-concrete floors for supporting the entire units were completed up to the bottom of the wheel cases. Then the wheel cases were set. After the cases were set the concrete piers and power-house floor were poured.

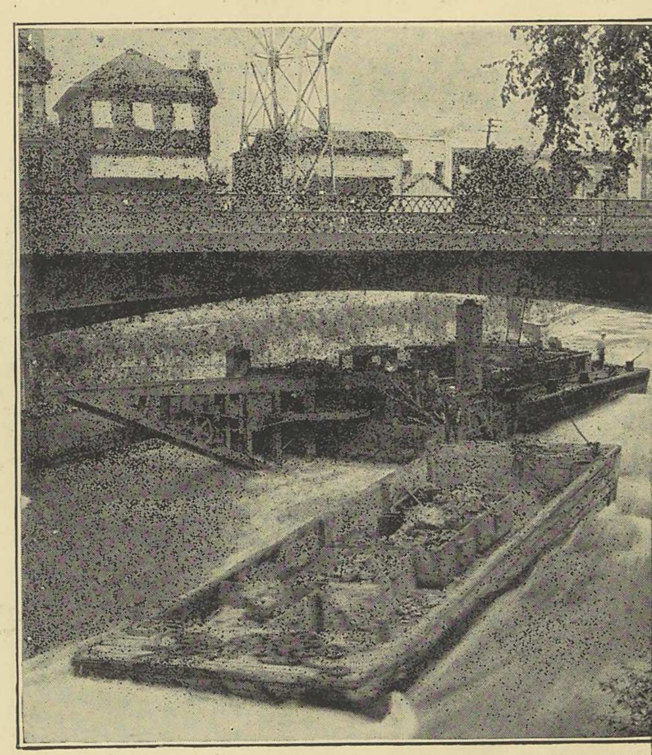


FIG. 40—LOW BOOM DREDGE FOR WORK UNDER BRIDGES

Manufacturers of all machinery were requested to ship in pieces not heavier than 50 tons, also that each piece must pass through a door 12 ft. wide and 16 ft. high.

The equipment for the power house was carried below the bank by means of a large 50-ton crane which is a permanent structure built in 1906 and was used in the construction of old Station No. 3. This 50-ton crane is operated over a crane runway, the westerly end of which is a cantilever extending 53 ft. over the edge of the cliff and running back easterly over the switchtracks which are about 200 ft. from the edge of the cliff. The crane has a 50-ton and a 5-ton hook with a total lift of 235 ft. By means of this crane all equipment was lifted from the railroad cars upon the switchtracks, carried out to the end of the cantilever and lowered 225 ft. below unto a car which runs on a standard-gage track into the south end of old Station No. 3 and there turns into the new station. Within the new station are two electric cranes of 100 tons each. By means of these cranes all parts of the equipment were easily carried from the car and distributed to their proper place in the power house. In the erection of the turbines and generators it was necessary as the parts were assembled to make lifts from 150 to 200 tons. This was accomplished by using the two cranes together by means of a large whiffle tree, which was a 200-ton capacity box girder beam arranged so that the two cranes should be readily hitched at each end with a large lifting hook in the middle of this beam.

Tunneling and Lining the Penstocks

Method of Driving Tunnels Up Through 350 Ft. of Rocks and Placing Penstocks Steel and Johnson Valve

BY G. W. HEWITT

Field engineer Niagara Falls Power Company, Niagara Falls, N. Y.

THE three penstocks of Station No. 3 extension are identical, and except for a few minor details during the construction, the conditions met were the same. Each tunnel was driven from the lower portal up through the rock to the top, a distance of 350 ft. Excavation started at the face of the deep excavation of the power house and ended at the face of the excavation of the forebay. The excavation of the bell-mouth section inside the limits of the forebay gatehouses was open excavation and was part of the excavation of the forebay.

The center line of tunnel was level at El. 353 to the P. C. of the lower curve, the P. I. of which was 86 ft. from the portal. At this point the line turned 18° 19′ to the right and 45° to the vertical, making the actual intersection angle 47° 50′. The two tangents were connected by a 40-ft. radius curve. The inclined section of tunnel was 45° to the vertical until the upper curve was reached, which also had a 40-ft. radius, and then into the open excavation of the bell-mouth section, the center line of which was El. 538, or a vertical distance of 185 ft. from center of lower horizontal section to horizontal section of bell-mouth.

The diameter of finished tunnel is 15 ft. 6 in. and the plans called for a minimum of 18 in. of concrete, making the excavation 18 ft. 6 in. in diameter theoretically, although sunflower cross-sections showed that the diameter of excavation averaged 20 ft.

Excavation was started at the lower portal, using four water Leyner column drills, and the entire heading, or upper half of the tunnel, drilled and shot. Disposal was made on the horizontal section by shovel-

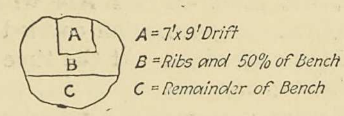


FIG. 42—STAGES IN PENSTOCK TUNNELING OPERATIONS

ing the rock into 4-yd. cars, which were hauled out by steam dinkeys. After the bench had been uncovered, it was then drilled and shot and the material disposed and the track run back. At the end of the horizontal section a heavy timber hopper was built under which the cars could be run and loaded so that after shooting the rock would roll down the 45° slope onto the hopper. Above this point and for the remainder of the tunnel, the drilling and shooting were done in three operations, as can be seen from the sketch shown above.

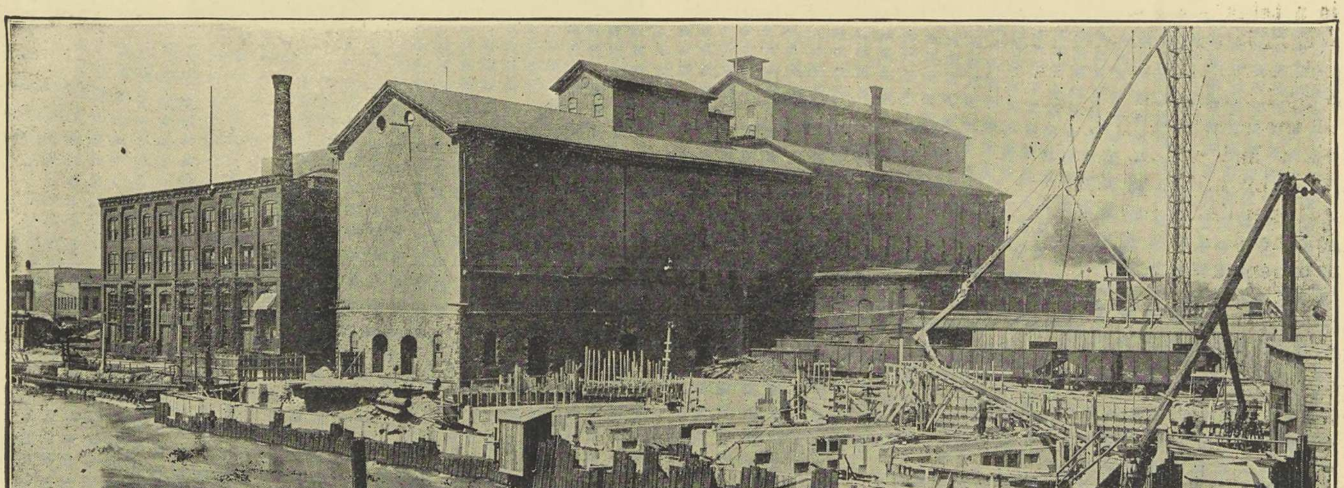


FIG. 41—COFFERDAM AT FOREBAY OF EXTENSION TO STATION NO. 3, NIAGARA FALLS POWER COMPANY

First a drift *A* approximately 7 ft. x 9 ft. was driven through to the upper portal, then the ribs and about 50 per cent of the bench *B*, and lastly the remainder of the bench *C*.

Excavation of the drift was naturally the most difficult operation, as the drilling and shooting of portions *B* and *C* more nearly approximated that of open excavation and were quite rapid. During excavation of the drift the work was carried on in two shifts of eleven hours each, working seven days a week. For the lower two-thirds of the 45° tunnel, each shift was able to drill and shoot a heading, averaging about 7 ft. each shot. Above that the progress slowed down owing to the difficulty of getting the heavy equipment of the 45° slope and also to the wet working conditions.

The drills, columns, and other equipment were hauled up the long slope by a rope passing through a block attached to an eyebolt in the roof. The planking and 8 x 8-in. timbers for staging were first hauled up and placed and the heading was then scaled, after which the columns and drills were hauled up and set up in place. The electricians and pipefitters went in as soon as possible after the rounds had been shot to make any repairs that had to be made to the lighting circuit and to the air and water lines.

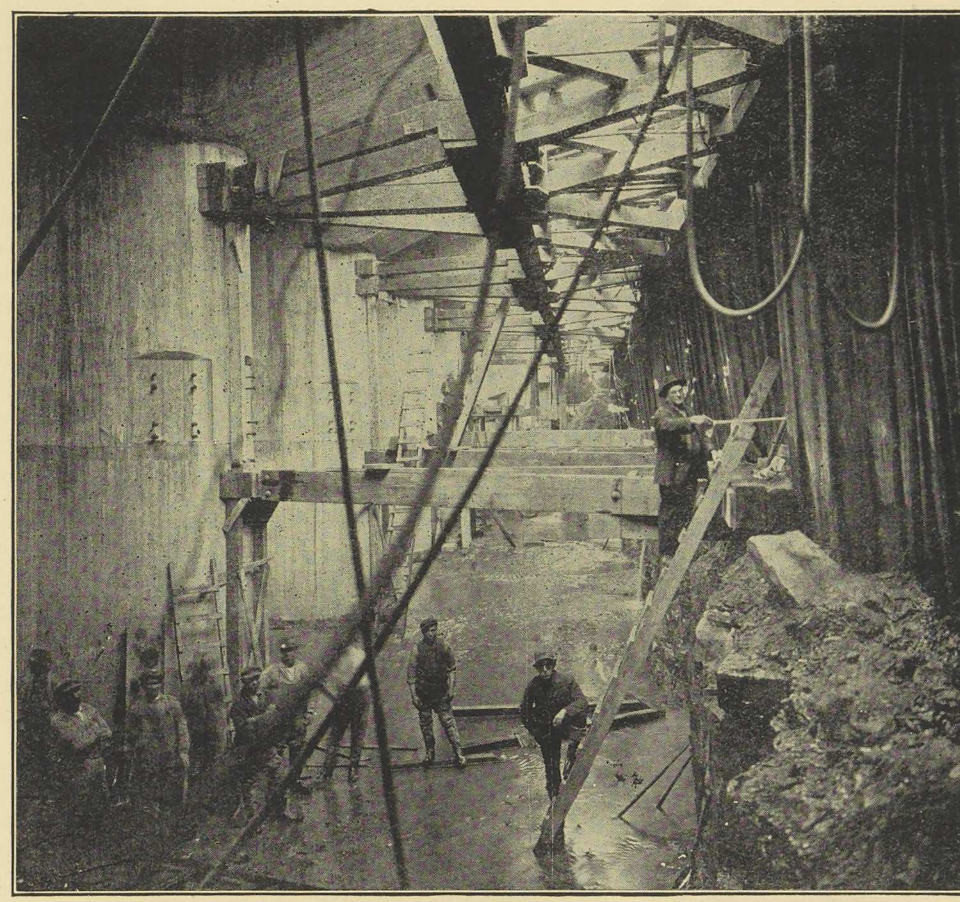


FIG. 43—BEHIND THE FOREBAY COFFERDAM

After about 100 ft. up on the incline the air became so bad that an exhaust fan had to be installed and an 8-in. suction pipe attached to the roof of the tunnel. An auxiliary pump also had to be installed to keep up the water pressure.

The field party consisted of a chief, a transitman, and two chainmen. They gave two headings in each of the three tunnels every day as a rule, checked their lines and bases, estimated quantities, etc. As a rule they laid out the grade and roof line while the drillers were getting their material together. Grades as well as line were given with a transit using the vertical arc and correcting for distance of set-up above center line, which on a 45° slope was normal distance times the secant of 45° (1.414) equals the vertical distance.

On the lower curve the horizontal and vertical projections were both parabolas owing to the circular curve being on an inclined plane. About five points on the curve were calculated for their projections and were then plotted up on cross-section paper and the curves were then drawn through them, prints made and furnished to the field party. In laying out the heading on the curve, the field party could always tell how far to the right and above the center of the horizontal section the center line was at the heading by picking the points of the curve without any long calculations of parabolic formulæ. They could also tell the heading foreman just how much he had to point his drills up for the next round of holes.

The rock on the lower horizontal section was hard Medina sandstone. Above this, at the upper end of the curve, was a thin layer of shale overlaid by about 12 ft. of the Clinton ledge of limestone. A small amount of seepage was encountered in this shale in each of the three tunnels, while in the first one a drill opened up a water pocket which flowed for about twenty minutes and had a very strong sulphur smell. Above the Clinton limestone the tunnel went through approximately 100 ft. of shale, which was soft and stratified at the lower end and which shaded into an unstratified slate just under the limestone at the top. For the remainder of the distance limestone was encountered, varying from hard blue limestone just above the slate to well-seamed limestone near the top. The slate formation underneath the limestone was so hard that the drillers insisted that they were in the limestone heading before they really reached it. The seepage in the upper part of the shale and lower portions of the limestone was such that it resembled a rainstorm, while considerable seepage was again encountered in the upper end.

The concreting of the lining was carried on in several independent operations in order to co-ordinate with the other work above and below the bank.

On the lower curve a 15-in. concrete invert section was first built with slots and pipe for the reinforcing. The wooden ribs were then set up and lined and then the wooden lagging placed. Two rows of circular reinforcing bars were then placed and the concreting done through chutes from the upper end of the tunnel. This

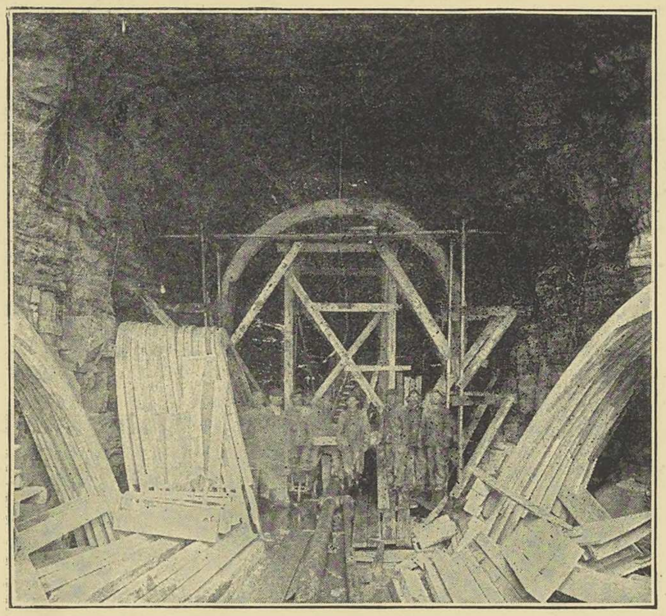


FIG. 44—TUNNEL HEADING OF PENSTOCK—OUTSIDE CUT ABOUT 20 FT. DIAMETER

section was the only one on which reinforcing bars were used.

The seepage was taken care of by an 8-in. wrought-iron pipe emptying into the tailrace. A T was placed at the end of every 20-ft. section and a short length of 4-in. pipe and elbow attached to each side. Just below each elbow a dam was built out of sacks of concrete and just before the concrete reached the top of them they were covered with a piece of canvas and a few more sacks of concrete, thus leaving a permanent drain.

The bell-mouth section was concreted around wooden forms with a bulkhead between each tunnel. Concrete was carried to a height of 25 ft. above the bottom in a solid mass. The first pour was about a foot above the bottom so that the forms would not float, the second pour to slightly above center line, and the last pour to about 4 ft. above the highest part. The steel guides for the gates, anchor bolts for the racks, etc., were all set in places before concreting.

It was the original intention to concrete from the top of the lower curve to the top of underground portion with steel forms and then to connect the tunnel concrete with the bell-mouth section with wooden forms on the upper curve. However, as it was deemed advisable to rush the steelwork of the gatehouse in order to be able to use the crane, it was decided to concrete in the entire upper curve before doing that of the 45° slope. This necessitated making the joining at the top of the slope entirely underground. Pipes were placed along the roof of the curved section so that the slope below could be concreted at the connection.

On the 45° slope Blaw-Knox steel forms were used, having a diameter of 15 ft. 6 in. and a length of 5 ft. Twelve complete sections of forms and five extra invert sections were used. Concrete in this section was continuous from bottom to top, never being less than four batches per hour or just enough so that the top concrete had not set up when a new batch was poured. It was found that by having the men walk around and stirring up the top that so-called mud seams or seepage rings were prevented from forming. Forms were only moved during the day shift and iron workers were employed for this work. After the first two days in getting acquainted with their equipment and making a few minor changes in the traveler, they averaged four sections or 20 ft. each day. The traveler was moved by a hoist at the top. Besides the crew of five iron workers on the forms, there was a concrete crew of three men taking care of the concrete as it came through the chutes from the top.

Lastly the steel lining was placed and concreted around. The steel plates were assembled under the crane in the Johnson valve chamber and when riveted were skidded back and new sections attacked. This steel lining extended 68 ft. in from the edge of the cliff. The diameter was 15 ft. 6 in. except where connecting to the Johnson valve, at which point it was 17 ft.

With the steel penstock in place the Johnson valve was next assembled and connected to the steel lining and the wheel case. Riveting was then completed, burnt rivets being cut out and replaced by new ones. In the majority of cases, however, it was found that the electric weld on the rivet gave excellent results and made a tight job.

After the riveting was completed and all connections made, the portion under-ground was concreted in, grout pipes being placed along the roof through which grout was afterward forced under air pressure to fill any cavities along the roof which could not be concreted. At the lower end of the curve, where the joints in the concrete were made, a small keyway was left which was painted with soft asphaltum to prevent leakage in case of contraction. Several boxes were also placed at the joint with $\frac{3}{4}$-in. pipe leading from them into the open at the testing chamber so that any leakage from contraction at the joint would show.

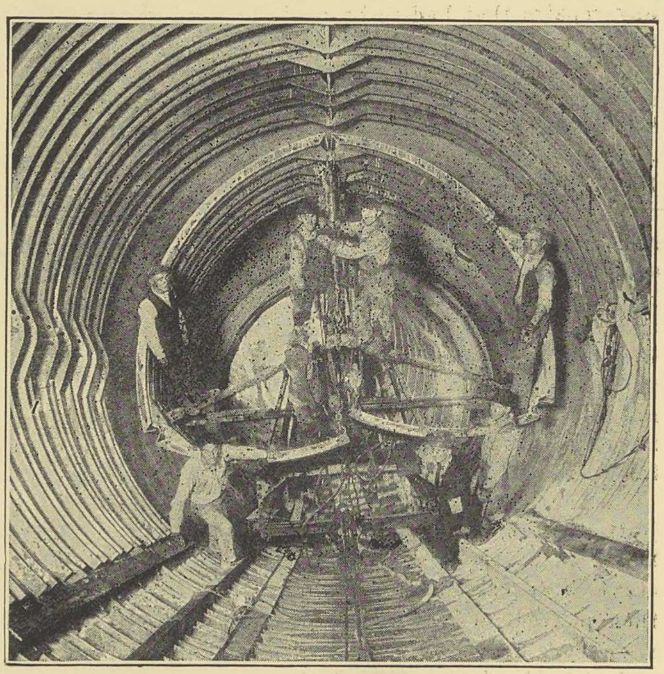


FIG. 45—FORM FOR CONCRETING PENSTOCK TUNNEL. CLEAR DIAMETER $15\frac{1}{2}$ FT.

Unit Idea in 100,000-Hp. Electrical Layout

To Assure Reliability of Service and Simplicity of Operation Each Unit Has Been Dealt with As Separate Plant

BY J. ALLEN JOHNSON
Electrical engineer Niagara Falls Power Company

IN THE design of the Station No. 3 extension careful attention was given to the logical and orderly placing and grouping of apparatus. On account of its large size each unit was, to a great extent, considered as a complete plant in itself, being provided with its own individual auxiliaries conveniently grouped about it. Thus, if one stands upon the operating gallery on the center line of a unit, in front is the passage to the thrust-bearing deck of the generator, with bearing thermometers and oil flow indicators in plain view. At the right hand, near the front of the gallery, is the turbine governor, with tachometer and pressure gages, and to the right of that a pedestal for the control of the penstock valve, which pedestal also carries an illuminated turbine gate-opening indicator. At the left hand is the exciter switchboard, containing exciter and fan-motor starting equipment, generator protective relays and generator field-circuit breakers. To the left of this switchboard stands the motor-generator exciter. Thus practically all devices requiring constant oversight or frequent manipulation are concentrated at one level where a minimum number of operators can attend them with a minimum of labor.

On the main floor under the gallery, directly beneath the governor, are the governor accessories, comprising tanks, valves, piping, etc., and beneath the switchboard are the electrical switches for exciter and fan control, and beneath the exciter the ventilating fan. Below the main floor the hydraulic passages, valve, penstock, etc., occupy one side and the passages for electric wiring and ventilation the other. Piping connections for oil, water and compressed air are on the right, all electrical connections on the left.

The first of the three generators, known as No. 16, was supplied by the Allis-Chalmers Manufacturing Company, the second, No. 17, by the General Electric Company, and the third, No. 18, by the Westinghouse Electric & Manufacturing Company. The three generators are similar in design, dimensions and characteristics, each manufacturer, however, having been allowed considerable liberty in mechanical design and in the treatment of details. (These will be discussed in separate contributions by F. D. Newbury, W. G. Foster and R. B. Williamson.) The units are of the vertical-shaft type, three-phase, 25 cycles, 12,000 volts, 150 r.p.m., Y connected. They are given two ratings, one corresponding to the point of maximum efficiency of the hydraulic turbines, called the "normal" rating, and in addition a "maximum" rating. The ratings follow:

Rating	Kw.	Pf.	Kva.	Amperes
Normal	24,000	.9	26,700	1,285
Maximum	26,000	.8	32,500	1,564

In addition it was specified that the generator should be capable of absorbing 36,000 hp. from the turbine.

The principal dimensions of the generators are as follows:

Outside diameter of frame	21 ft. 6 in. to 21 ft. 9 in.
Height to top of frame	9 ft. 5 in.
Height to thrust-bearing deck	13 ft. $2\frac{3}{8}$ in.
Height over all	20 ft. $2\frac{1}{2}$ in.
Rotor diameter	16 ft. $2\frac{7}{8}$ in. to 16 ft. $5\frac{1}{2}$ in.

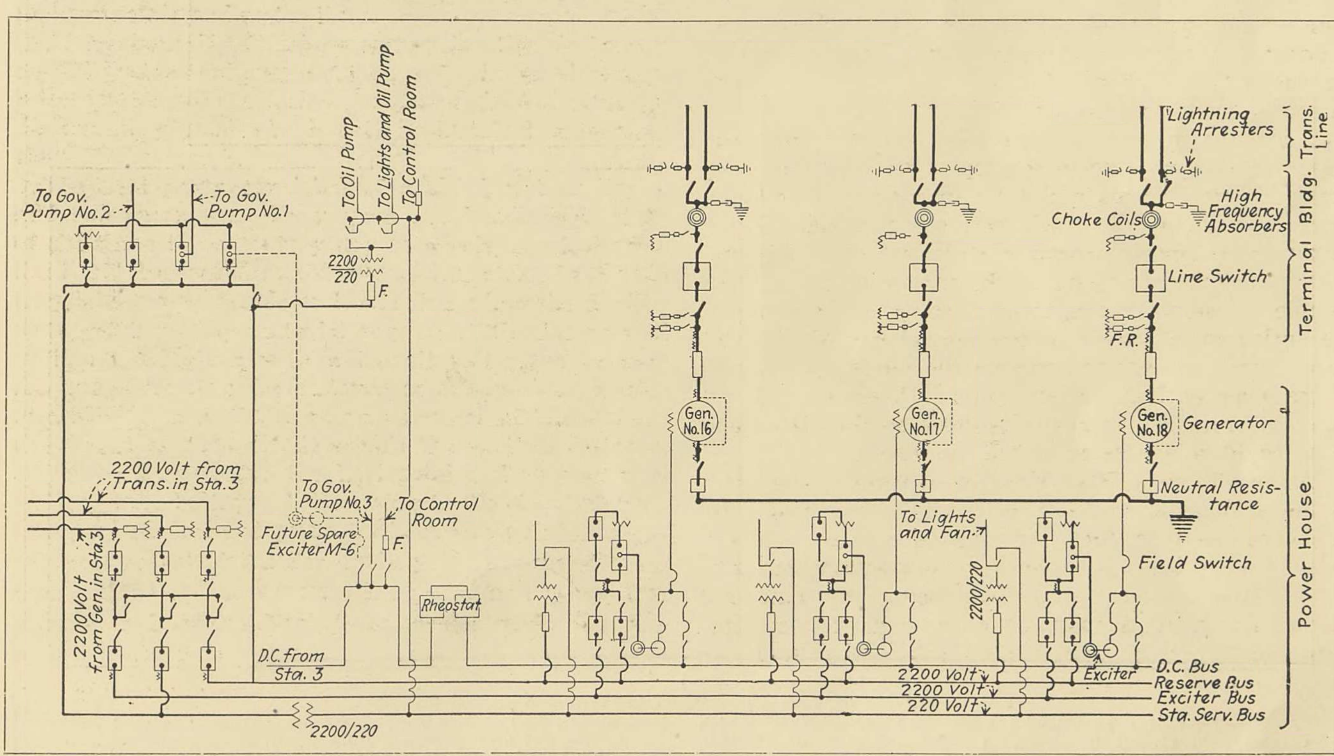


FIG. 46—SINGLE LINE DIAGRAM OF GENERATING STATION CIRCUITS

Only Equipment for Starting and Stopping Is in Operating Room—Control Apparatus Is in Control Room

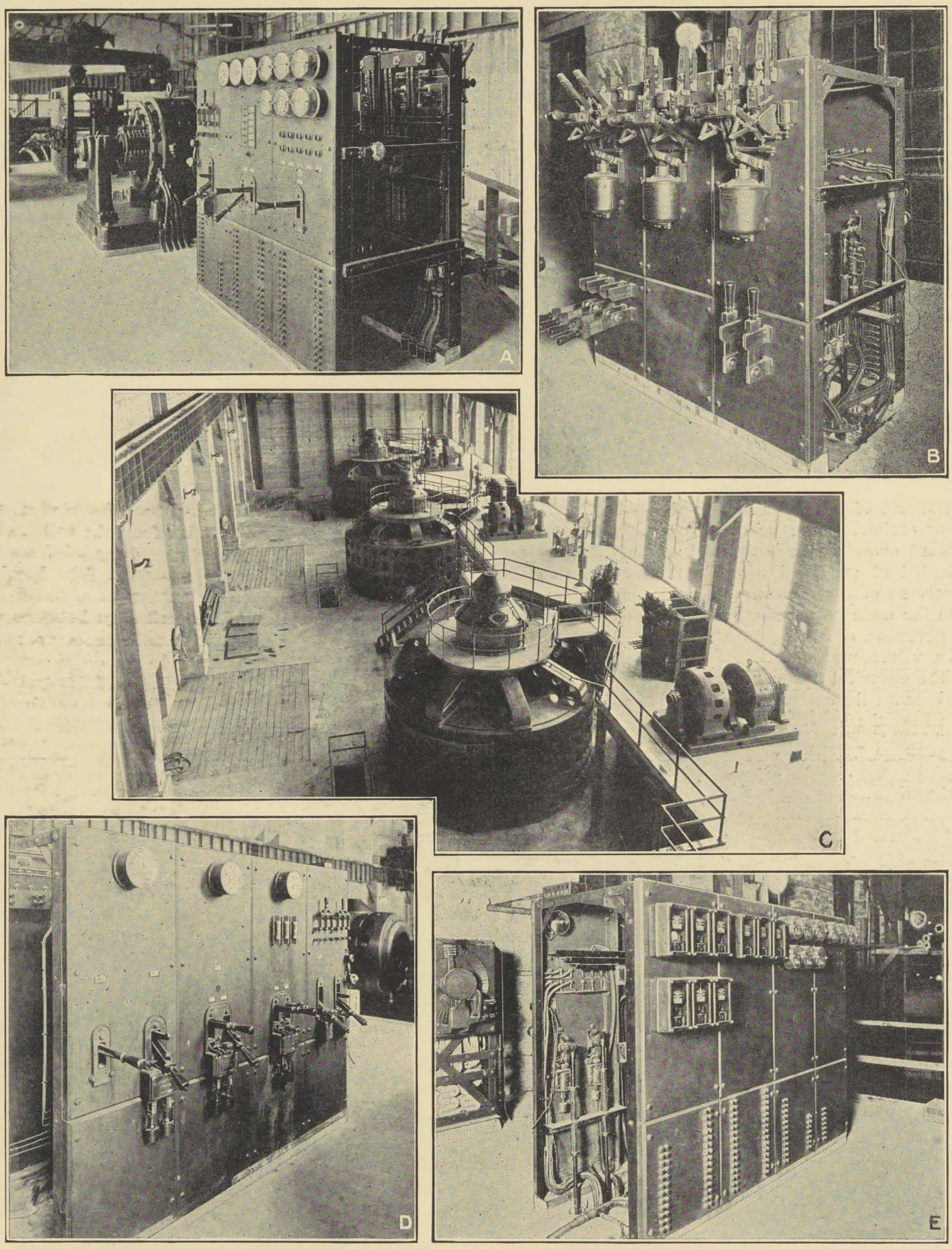


FIG. 47—SOME OF THE EQUIPMENT OF THE OPERATING GALLERY

A—Exciter-motor panelboard back to back with B, which carries field circuit breakers. C—General view of station. On the gallery are the governor heads, motor driven exciters, field circuit and station service panelboards and related equipment. D—Oil and governor fluid pump motors are controlled from this board. Back to back is E, station-service relay board.

The estimated weights of the principal parts in pounds are as follows:

	No. 16	No. 17	No. 18
Stator with core and windings....	224,000	251,000	291,000
Rotor with shaft................	271,000	311,000	318,000
Miscellaneous parts..............	90,000	53,000	41,000
Total	585,000	615,000	650,000

In each case the weight of the revolving part is carried by a Kingsbury thrust bearing mounted upon a massive spider on the top of the generator. These bearings are identical in the three different machines furnished by the various manufacturers.

Mica insulation was used for the armature windings of all three machines. Rotors were all designed for 100 per cent overspeed. Guaranteed efficiencies at normal load were 97 to 97.25 per cent and armature reactances not less than 18 per cent at the maximum generator rating.

Alternative Sources of Excitation Provided for Each Generator

An in dividual motor-driven exciter is provided for each generator. The motors are 2,200 volt, three phase, 25 cycle, 750 r.p.m.; the exciters 220 volt, 225 kw. shunt wound with series interpoles.

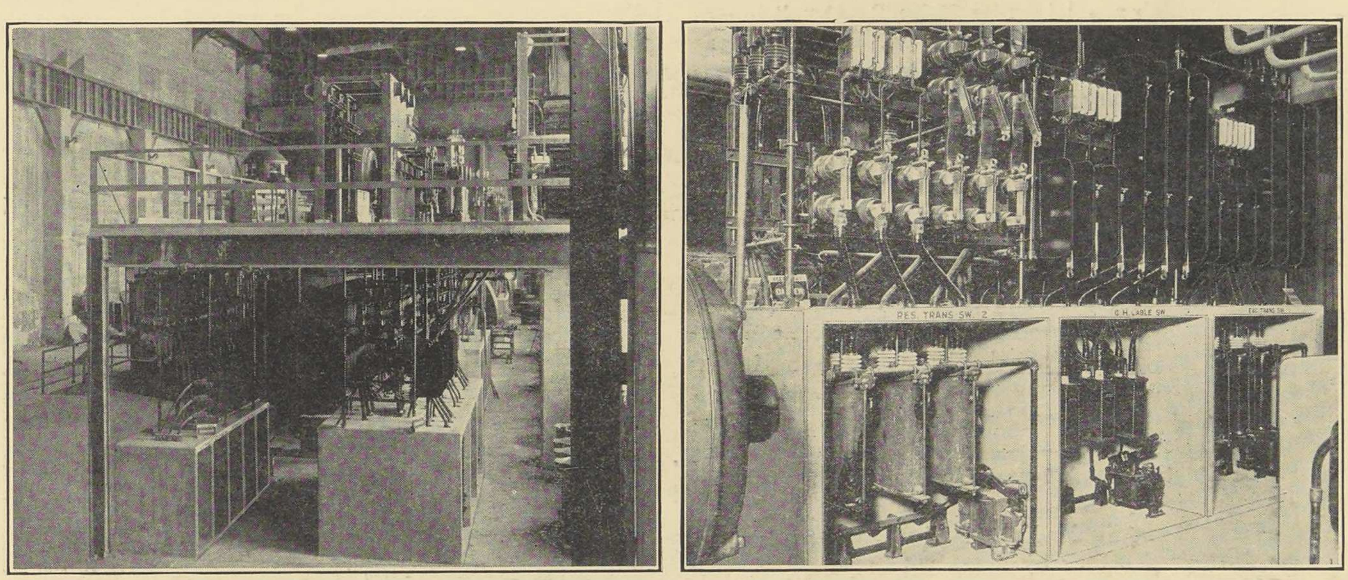


FIG. 48—END VIEW OF OPERATING GALLERY AND SECTION OF EQUIPMENT BELOW IT

There are two alternative sources of supply for the exciter motors. (See the general wiring diagram.) One of these comes from a special 2,200-volt waterwheel-driven generator installed for this service; the other is connected through transformers to the 12,000-volt buses of Station 3. Provision is made for a third connection to the present 2,200-volt distribution circuits in Station 3 gate house.

As a further reserve, there is also an auxiliary field circuit connecting to the direct-current buses of Station 3, capable of supplying the field of any one of the three new machines through a single field rheostat and direct-current bus. A controller for this rheostat is placed on the control board of each generator in the control room.

All of the exciter circuits with the exception of the motor-starting equipment are controlled from the control room at the top of the cliff back of the power house. The exciter motors are started from the unit switchboards on the gallery.

Eighteen Temperature Detectors in Each Generator

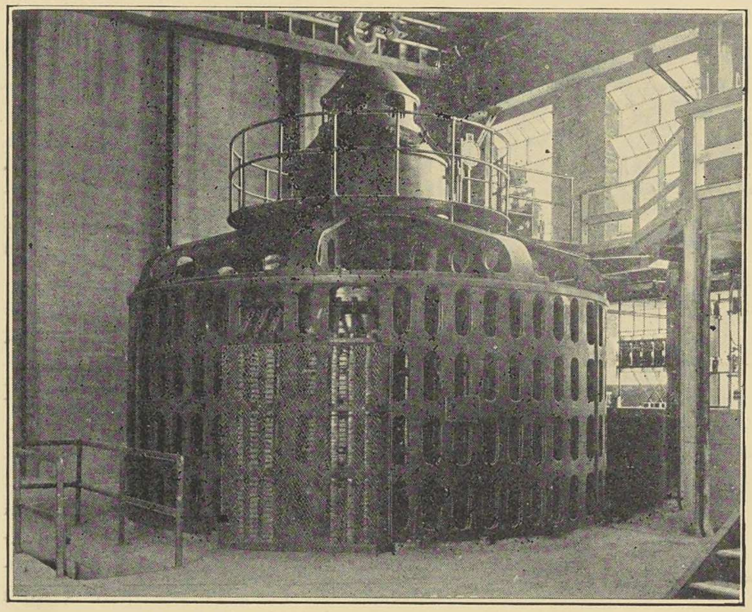
Each machine is equipped with eighteen embedded temperature detectors, whose leads are brought to terminals on the exciter switchboards, from which any six can be connected to temperature indicating devices in the control room. Cooling air is taken by the generators from the generator room at both top and bottom of the machine. The hot air discharging through the ventilating ducts is collected by a plate steel housing completely surrounding the generator frame and connecting to the inlet of a large motor-driven blower which exhausts the hot air, discharging it through a duct below the power house floor to an uptake leading to the outer air at the roof. Thus the hot air delivered from the generators is not permitted to enter the generator room. Means are provided, however, for recirculating any desired portion of this air during cold weather for the purpose of maintaining the temperature of the generator room at any comfortable working temperature desired.

The generators are protected as to internal breakdowns by means of the Merz-Price system of relays operated from two sets of current transformers, one installed at the neutral point and one in the phase leads, these relays being arranged to trip the line and field circuit breakers simultaneously. Overcurrent relays are also provided to trip the line circuit breakers in case of a short circuit. All relays are of the inverse definite time type.

Alarm signals are arranged to give warning of the failure of oil or governor fluid supply or the supply of water for the lubrication of the lignum vitæ turbine bearing.

Generator Auxiliaries

"Turbo-conoidal" ventilating fans made by the Buffalo Forge Company and rated at 90,000 cu. ft. per minute are directly connected through Franke flexible couplings to Allis-Chalmers 40-hp., 220-volt, 25-cycle, 288-r.p.m. induction motors. Starter handles are mounted upon the exciter switchboard on the gallery.



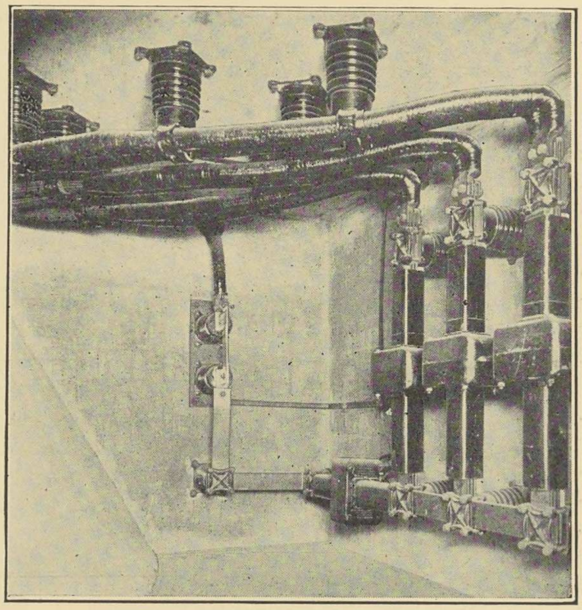


FIG. 49—METHOD OF CONDUCTING LEADS FROM GENERATORS

Six leads leave each generator. Three are main leads while the other three are the opposite ends of each phase and go through current transformers under the floor and thence to a neutral grounding switch as shown at the right. These current transformers are set for differential relay protection, and there is also another set in the phase leads.

There are three governor fluid pumps, centrifugal type, two of which are driven by 75-hp. 2,200-volt induction motors and the third by a 220-volt direct current motor. One of the alternating-current motors is manually started from the operating gallery. The second is equipped with automatic starting actuated by a float switch in the sump tank. The direct-current pump is also operated by a float switch adjusted to follow the automatic alternating-current pump. With these arrangements failure of governor fluid supply is practically impossible.

Bearing oil for all three units is handled by two 220-volt alternating-current motor-driven centrifugal pumps, both manually started. Provision is made for the addition of a third pump to be direct-current operated. Oil storage is provided sufficient for one hour normal operation of the entire plant, by means of tanks supported in the roof trusses above the generating station.

The 220-volt supply for lights and pumps and fan motors is furnished either by a central bank of 100-kva. 2200/220-volt transformers or by an individual bank of 15-kva. 2200/220-volt transformers for each unit. Energy for lighting is distributed to panel boxes at 220 volts, single phase, a balancing coil of 1.5-kw. capacity being installed at each box to supply the 220/110-volt three-wire branches, all lamps being 110 volts.

From the terminals of the generators cables lead to the top of the cliff, where the wires enter a terminal building containing switching, metering and protective equipment and from which lead the overhead transmission lines. A control building, also located at the top of the cliff, houses the control switchboards, space being provided here for the control of possible future units and also for the control of the units in Station 3, which are now controlled from a switchboard in the old generating station.

Terminal Building on Cliff Above Station

Owing to the fact that all of the power from the new generators was to be transmitted to a new substation at Echota (three miles distant), where complete paralleling arrangements were to be provided, it was not considered necessary to parallel the generators at the generating station, with the duplication of switching equipment and building involved therein. Each generator therefore feeds directly, without interconnection, to its own individual transmission line leading to the Echota substation, a single oil circuit breaker being interposed between the generator and the line. Arrangements are made for synchronizing at this breaker, but it is anticipated that the synchronizing will usually be done at the substation.

FIG. 50—CONTROL CABLES ARE RUN UP THE CLIFF IN CONDUIT

The terminal building is a long narrow structure located on the brink of the cliff above the generating station and was designed to house the generator oil switch and protective equipment, to serve as a terminal structure for the transmission lines and to form part of a future step-up transformer station.

On the first floor of the terminal building are installed current and potential transformers for metering purposes and the line circuit breaker. Choke coils and static absorbers for lightning protection occupy the second floor, and lightning arresters are situated on the roof. A somewhat unique feature of this installation is the location of the circuit breaker in an opening in the wall of the building in such a way that the tanks and mechanism communicate to the outside of the building, while the terminals and high potential connections are inside. This is primarily for protection against oil fires and explosions. The switch is a Westinghouse type CO-2, the choke coils also being of Westinghouse construction. The static absorbers and lightning arresters were furnished by the General Electric Company, the latter being of the oxide-film type.

The main leads from the generators, after passing through the current transformers for the operation of differential relays, which are located in the basement of the generating station, enter 1,250,000 circ. mil., single-conductor, varnished-cambric insulated, lead-covered cables, two for each phase, leading to the power house roof. At this point the conductors emerge from the lead-covered cables and pass out of the building through bushings and connect to open wires leading to the terminal building at the top of the cliff. The lead-covered cables are installed in slots in the concrete construction of the power house, and where these slots are vertical the weight of the cable is supported by cast-iron wedges inserted between the cable and the sides of the slot, which for this purpose are provided with beveled pockets at intervals of 8 ft. This method of supporting vertical runs of cable has been very successfully used in the Hydraulic Power Company's previous installation.

The terminal building, at the top of the cliff, is constructed with a cantilever extending out over the edge of the cliff, forming a platform, to the under side of which are attached the open wires leading up from the power house. From this point the leads enter the terminal building through bushings under the overhanging platform. The open wiring between the power house and terminal building is supported on suspension-type strain insulators and is protected against lightning by overhead ground wires. Provision will be made for circulating low-voltage current through these ground wires in winter to prevent the accumulation of sleet.

ARRANGEMENTS FOR CONTROL WIRE RUNS

The control wires from the power house apparatus are first brought to link terminals mounted upon the exciter switchboard on the power house gallery. From this point multiple-conductor control cables carry the control wires to similar terminals on the relay boards in the control building. The control wire passage, which joins the rear power house wall at the level of the roof trusses, is of concrete, built upon the sloping rock surface between the power house and the bottom of an old tailrace shaft which is used to carry the control wiring up the cliff. In this control-wire passage and shaft the cables are inclosed in steel conduit, which, in the vertical portion, is clamped to a steel tower. This tower is supported from the bottom and is free from the side walls of the shaft in order to protect the cables against seepage. A stone wall has been erected across the open side of this shaft, which originally was merely a slot in the vertical face of the cliff.

From the top of the shaft the control wires are carried on steel work through existing excavation to the basement of the control building and thence to terminals upon the relay boards. An underground passage also leads to the terminal building. These passages will be utilized both for control wiring and as a subway connecting the control and terminal buildings.

Wherever the concentration of control wiring would result in congestion if placed in conduit the control wiring is carried in steel pans or troughs, arranged one above another, each pan being assigned to an individual unit. In this manner the congestion of conduit, so often seen in power plant construction, is entirely avoided, with, at the same time, a distinct gain in accessibility. Wherever necessary for protection, or where the use of the pan construction is undesirable, control wires are carried in steel conduit. Control wiring is made up in cables of seven to fifteen conductors, each conductor being covered with rubber and cotton braid, the cable being covered with flame-proof braid. No lead sheaths were used on the control cables.

NEW CONTROL BUILDING FOR ENTIRE PLANT

The control building is located upon the brink of the cliff, overlooking the lower gorge, at a point immediately above the junction of the old and new generating stations, where it is most conveniently situated to control both the old and new plants. The building stands directly over the discharge from the ice gates of Station 3, and use was made of some old waterways, dating from days prior to the art of electrical generation, for control wire passages to the generating and terminal stations.

The main generator control switchboards, which are

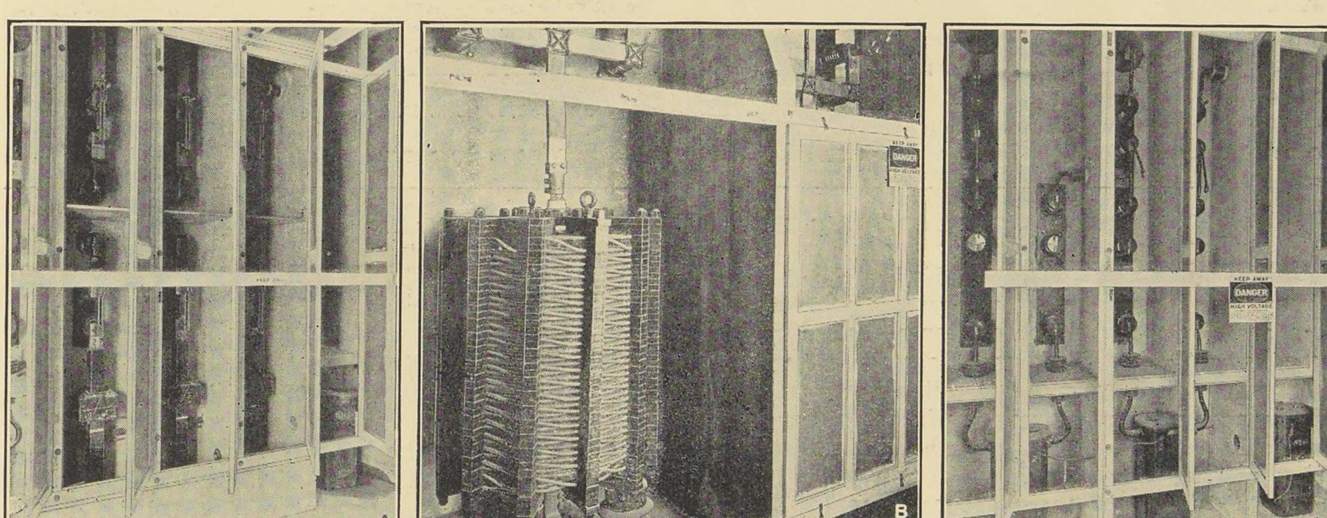


FIG. 51—CELL CONSTRUCTION INSIDE TERMINAL BUILDING ON CLIFF ABOVE STATION

A—Disconnecting switch compartment. Observe that the compartment doors are hinged and those in same circuit group are attached to bar and interlocked so that when oil switches are closed the doors cannot be opened, and hence the maximum protection is afforded workmen. B—One of the choke coils in the generator circuit. C—Potential transformer compartment.

located in the control building, are of the utmost simplicity. Vertical panels are used, of natural, dull-finished black "Linstun." Each unit control consists of three panels, one containing the voltage regulators and temperature indicating devices, the second the main generator instruments and control switches for exciter and field circuits and governor speed control, and the third, the generating station signal system and control switch for the line circuit breaker. The boards are arranged upon a circular arc, space being provided both for considerable extension of the new station and for the entire control of the old, which it is intended ultimately to relocate at this point.

On the lower floor of the control building, directly beneath the generator control boards, are panels for control wire terminals, relays and recording instruments. Here are also mounted the exciter rheostats operated from the control boards above. A storage battery rated at 120 amp.-hr. capacity at 220 volts for control circuit operation occupies a battery room in one corner of this floor, and immediately adjacent thereto is installed a 16-kw. motor generator set for charging purposes.

In addition to the main generator control switchboards in the control room there is also a six-panel service switchboard for storage battery control and charging and for direct-current control, alternating-current lighting and heating circuits in the control and terminal buildings and a three-panel board for the control of the 2,200-volt circuits for the supply of power for excitation and service in the generating station. All switchboards were furnished by the Westinghouse Electric & Manufacturing Company, after plans and specifications of the power company.

From the foregoing description it will be noted that the entire control of both main generator and exciter circuits, with the sole exception of the exciter motor-starting equipment, is in the hands of the control room operator. First, he may select the source of 2,200-volt power for excitation, *i.e.*, 2,200-volt generator, Station 3 bus, or gate-house service bus. Second, he may select the source of power for driving the exciter for each generator, *i.e.*, exciter bus or reserve bus. Third, he may select the source of direct-current power for each generator field, *i.e.*, individual exciter or direct-current bus. Fourth, he has full control of generator fields, either through the individual exciter field or through the common main field rheostat, and of the field switch. Fifth, he has control of the turbine governor for varying the load and synchronizing, and, finally, of the main generator oil-circuit-breaker connecting the generator to the transmission line.

The duties of the generating station operator are, therefore, confined to starting and stopping the apparatus and attention to its proper mechanical operation,

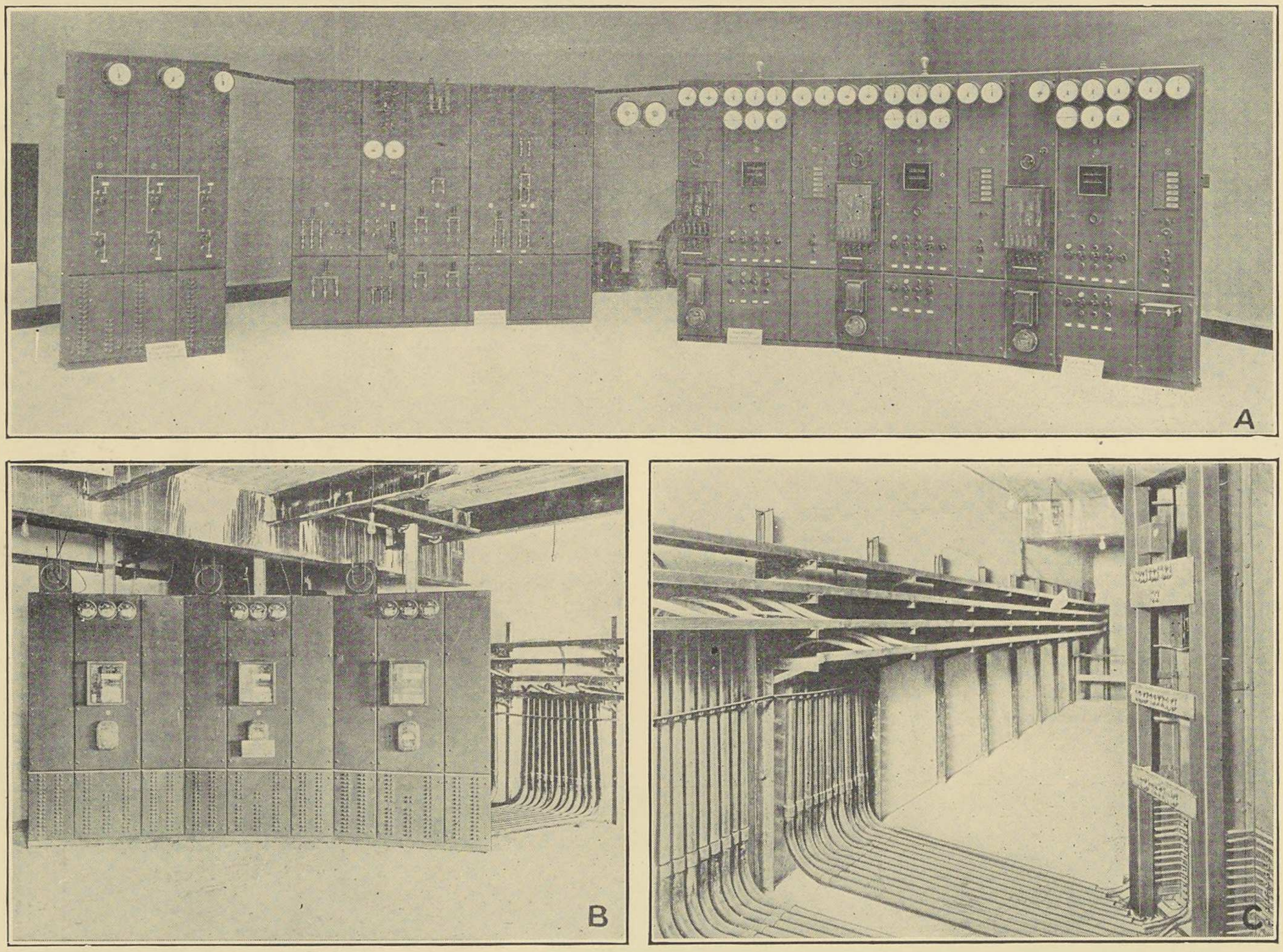


FIG. 52—SIMPLICITY OF LAYOUT AND ACCESSIBILITY OF EQUIPMENT ARE EVIDENT IN DESIGN OF CONTROL HOUSE

A—Main control room showing oil-switch control handles, instruments for operating units, signal apparatus. Tirrill regulators and annunciators which indicate location of trouble. On the left side of the desk is a roll chart on which is plotted a station-log. Below this room is the board shown in B, which carries relays and recording and integrating meters. The cables coming to this board are supported in troughs along the walls, as shown in C. Back of the panels to which the cables lead are conduits.

600,000-Hp. Line Delivers Niagara Power

Six Circuits Spaced for 88,000 Volts Are Supported on Cantilevers Overhanging Hydraulic Canal—Special Precautions to Guard Against Failure

By J. ALLEN JOHNSON
Electrical engineer Niagara Falls Power Company

THE problem of transmitting the 100,000 hp. generated in the Niagara Falls extension was complicated by many factors. In the first place the prospective load for this development was concentrated within a comparatively narrow area adjacent to the upper river, so that it was necessary that the entire output should be transmitted in a single direction. The city has few available streets leading in the desired direction, and most of these were already occupied by conduit systems.

As a second consideration, the character of the load, which has a daily load factor of over 95 per cent (the power being mostly used for electrochemical and electrometallurgical purposes), is the worst possible for underground transmission because the constant generation of heat in the cables causes a considerable reduction in their transmitting capacity compared with that on a system of low load factor.

As a third consideration, a glance into the future indicated the probability of a much larger transmission of Niagara power to Buffalo in the not distant future, requiring a much higher voltage than that used for local distribution. In this event the proper location for the step-up transformers would be close to the generating station. A 3-mile (4.2-km.) underground transmission to Echota, the center of load, at generator voltage before stepping up would be economically unsound. Furthermore it appeared very probable that additional development of power at this point would be required in order to meet the double demand for more power on the one hand and increased economy in use of water on the other. Overhead transmission would permit the necessary high voltage for long-distance transmission and would also provide the necessary flexibility to care for future increases in power development, either by adding more circuits or by raising the transmission voltage. In addition to all other considerations, cost estimates showed a differential in favor of overhead transmission of about one to three, which under the existing conditions of high costs was an extremely important consideration. Fortunately, the company already possessed in its canal right-of-way through the city a possible outlet for overhead lines if a way could be found to utilize it without interfering with its use as a waterway. As finally constructed the transmission line has a length of 16,000 ft. (4,800 m.) and runs from the terminal building up the canal to the river, thence following the bank past the plant of the old Niagara Falls Power Company (now known as the Niagara plant) and finally turning away from the river again at Echota to connect with the Echota substation.

The solution of the transmission problem was greatly facilitated by the consolidation of the two power companies inasmuch as land for the location of the line for the greater part of its length was already in possession of one or the other of them. For a distance of approximately 4,000 ft. (1,200 m.) through the heart of the city, however, it was necessary to make use of the property already occupied by the hydraulic canal. The accompanying halftone illustrations show clearly how this was accomplished by means of steel cantilevers anchored into massive concrete foundations on one bank of the canal, upon which were erected the six-circuit transmission towers.

For the greater part of the distance it was only found necessary for the narrow bases of the towers to be placed over the canal right-of-way, easement being obtained from abutting property owners for the overhanging portion of the construction. At the large bridge spanning the canal at the junction of Third and Niagara Streets, however, this was not possible, and it was necessary to place two towers entirely over the canal. This was accomplished by means of cantilevers extra heavily braced.

The main horizontal members of this structure are composed of two 30-in. (75-cm.) I beams, each 60 ft. (18 m.) long, placed side by side. Thirty feet (9 m.) of these beams is buried in the massive concrete foundation, the other 30 ft. projecting out over the canal. In these structures the center line of the towers is 25 ft. (7.5 m.) from the face of the canal wall. A heavy brace was added to these special structures to give stability and rigidity, although not needed for strength. In the case of the short cantilevers the brace was omitted.

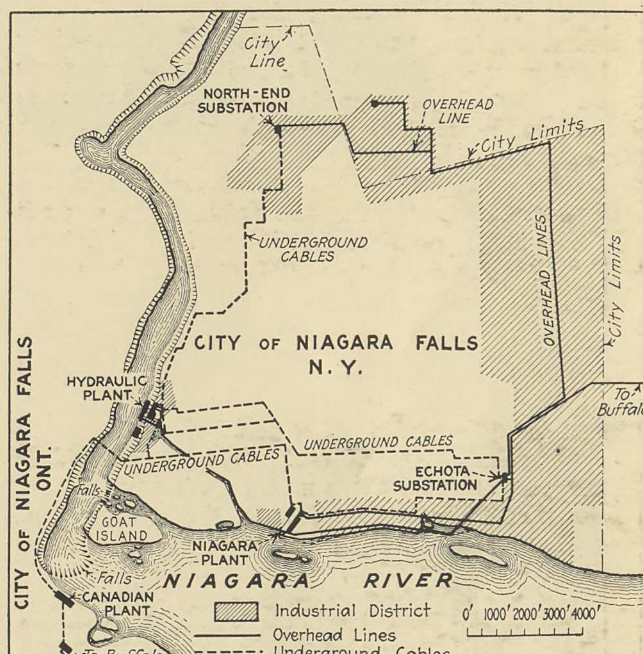
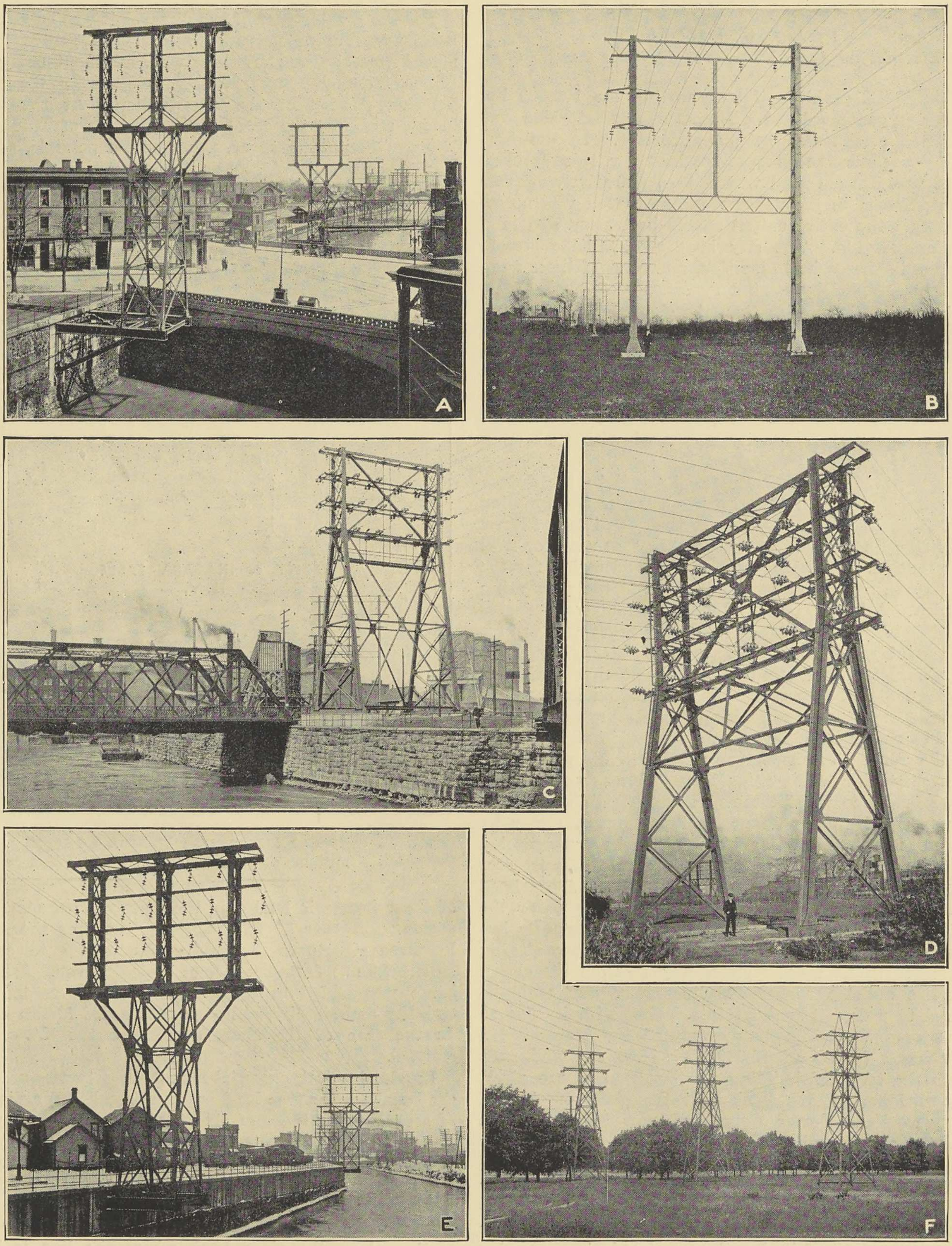


FIG. 53—ROUTES FOLLOWED BY PRINCIPAL TIE LINES AND FEEDERS OF NIAGARA FALLS SYSTEM

In addition to the special narrow-base towers used on the canal section, the local conditions called for the use of several other types of structure. In full-strain positions three different types were employed, the standard-strain type, portal strain, and two-circuit strain. Between strain points the line is supported on flexible steel bents of portal construction.

The portal type of construction was used for the section along the river bank where the line is built over a future street. For a distance of approximately 1,000 ft. (300 m.) the land which this street is to occupy has not yet been filled in, and the towers were erected on heavy concrete abutments constructed in the

Fig. 54—Tower Construction Used to Support Six Circuits from Niagara Falls 100,000-Hp. Extension to Echota Substation



A—Tower on cantilever support for extreme overhang.
B—Straightaway towers supporting six circuits.
C—Angle tower at road crossing.
D—Portal tower over main roadway.

E—Cantilever bracing was omitted where overhang was not excessive

F—Double circuit anchor towers used for proper distribution of lines at Echota Substation.

bed of the river. One of the towers so placed was a full-strain angle tower.

At the substation end of the line three two-circuit strain towers were used in order to provide for the proper distribution of the circuits at the substation wall. As may be observed the line comprises six three-phase circuits, each consisting of 500,000-circ.mil stranded medium-hard-drawn copper. At present two circuits are used for each 32,500-kva. unit at 12,000 volts, but clearances are provided for 88,000 volts. At 44,000 volts each circuit will have a nominal capacity of one unit of 32,500 kva., and at 88,000 volts each circuit will, if necessary, easily handle the output of three such units, or 97,500 kva. At 88,000 volts, therefore, the capacity of the six circuits will be 585,000 kva., or, roughly, 600,000 hp. It is believed that this is by far the largest capacity for which a transmission line was ever constructed.

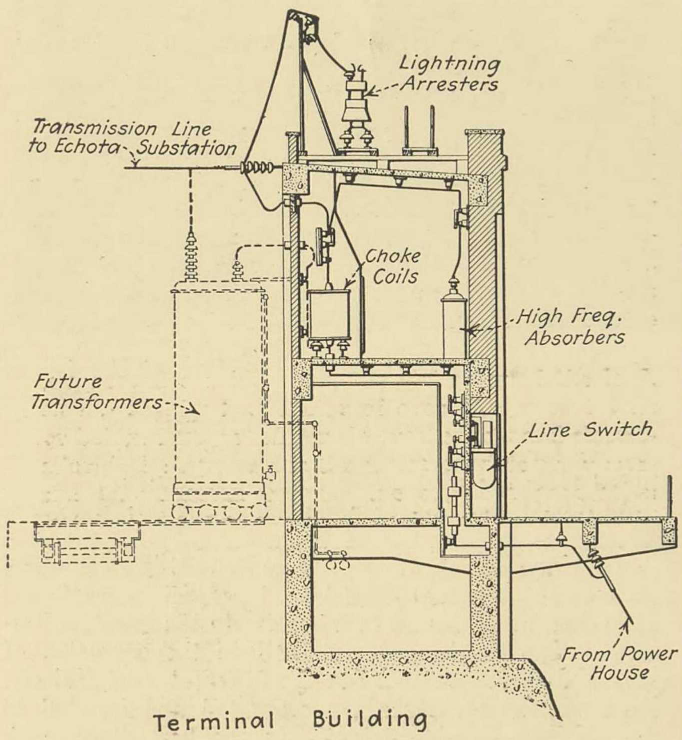


FIG. 55—CROSS-SECTION OF TERMINAL BUILDING FROM WHICH LINES RUN TO ECHOTA

Owing to the fact that this line passes through the business portion of a busy city, special precautions were taken to guard against failure. Although the ultimate strength of each conductor is over 20,000 lb. (9,000 kg.), they are strung for a maximum tension under worst conditions of wind and ice of only 6,000 lb. (2,700 kg.). At strain towers double-strain insulators are used having a strength approximately equal to that of the conductor. Short spans, not exceeding 350 ft. (105 m.), were used as a further contribution toward safety and stability.

The line is insulated with Jeffrey-Dewitt suspension-type insulators, two units being used in suspension strings and three in strain. Each of the insulator units was tested electrically to flash over at not less than 90,000 volts and also to a mechanical tension of 8,000 lb. (3,600 kg.). On the canal section, because of the peculiarities of the right-of-way, it was impossible to avoid a number of small angles, at which points suspension strings with hold-downs were used.

Insulator clamps, strain yokes and other miscellaneous insulator hardware were furnished by the Locke Insulator Manufacturing Company.

The line is protected against lightning by five overhead ground wires. On about half the line, where no corrosive fumes from chemical plants were to be expected, $\frac{3}{8}$-in. (9.6-mm.) galvanized Siemens-Martin steel-strand was used. For the second half, where the line passes in close proximity to the chemical plants, $\frac{3}{8}$-in. copper-clad wire was used for this purpose.

At the terminals of the line, at the terminal building and the Echota substation, the lines are first dead-ended on steel towers at some distance from the building and then looped to eye bolts embedded in the building construction, which is especially reinforced to withstand the tension of the conductors.

The proposal to mount the heavy towers on cantilevers along the bank of the canal came from R. L. Allen of the Archbold-Brady Company of Syracuse, to whom also is due the excellent and pleasing design of the towers. The company named furnished the towers for the entire line.

Clearing House for Five Stations

To Handle Output of Installations with Combined Rating of 400,000 Hp. Many New Ideas Have Been Incorporated—Unit Layout Employed

By J. ALLEN JOHNSON
Electrical engineer Niagara Falls Power Company

WITH the completion of the new development and following the consolidation of the Niagara Falls Power Company, Hydraulic Power Company and Cliff Electrical Distributing Company under Hydraulic Power Company control the Niagara Falls Power Company (consolidated) controls five generating stations having a combined rating of slightly over 400,000 horsepower. These are as follows:

Hydraulic Plant—Station No. 3 (A.C.)	90,000	H.P.
Hydraulic Plant—Station No. 3 Extension	100,000	"
Niagara Plant—Power House No. 1.	50,000	"
Niagara Plant—Power House No. 2.	60,000	"
Canadian Plant	110,000	"
	410,000	H.P.

The map Fig. 53, shows tne locations of these stations and also indicates the network of lines by which they are tied together and to the distributing center at Echota.

The Echota substation of the Niagara Falls Power Company is intended to serve three functions—(1) to subdivide and distribute the power from the new plant, (2) to serve as a clearing house for the output of the five generating stations, aggregating 400,000 hp., and (3) to act as a future stepdown transformer station.

Inasmuch as the primary function of this station is to distribute the power of the new plant, it was decided to preserve the unit arrangement in its construction. The station was accordingly laid out in units of a nominal capacity of 32,500 kva. Five of these units were constructed, three for the new plant and two for interconnection with other generating stations. A control building containing the switchboard apparatus was also erected. The general wiring diagram shows the arrangement of the main circuits; the physical layout of the structure is similar to that of the diagram. The general scheme is that of a main tie bus running lengthwise of the building with the unit lateral buses joining

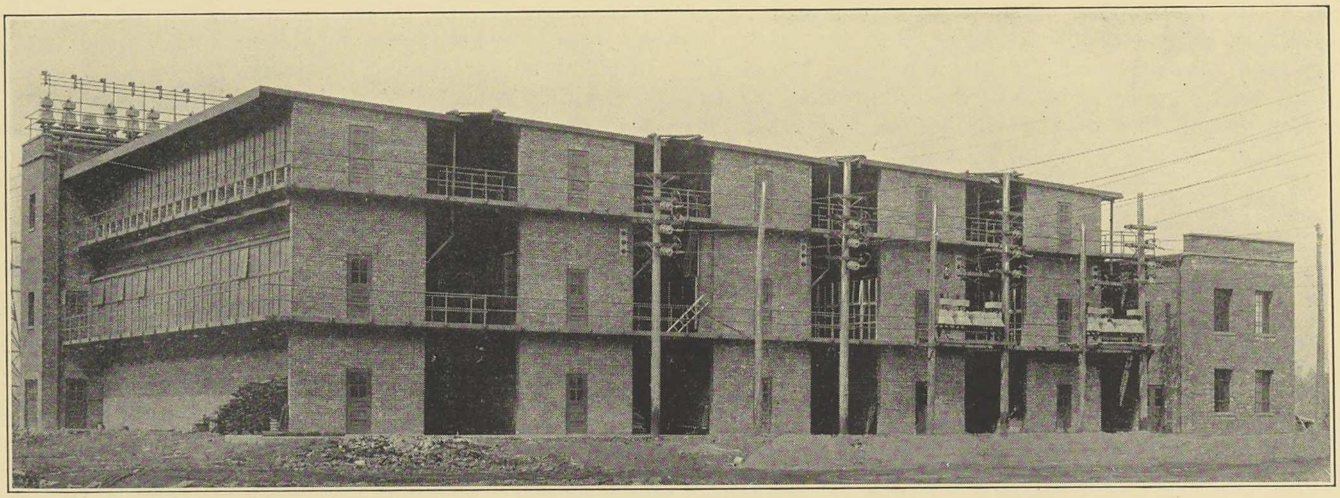


FIG. 56—EXTERIOR OF ECHOTA SUBSTATION, SHOWING FIVE SWITCHING BAYS AND OUTGOING OVERHEAD LINES

it at right angles. In this manner the over-all length of the building was very materially reduced and the spacing between units kept down to just about that which will later be required for the step-down transformers, specifically 26½ ft. (8 m.).

The prime consideration in the general layout of this station was provision for growth. The various elements of the structure are so placed that each one is capable of almost unlimited extension without interfering with the others; that is to say, each of the power units can be extended, the number of such units can be increased, and the length of the control building which houses the switchboards can also be increased accordingly, without interference with one another.

The five units or bays and the control building are connected at one end by a narrow building or passageway which contains the incoming line protective equipment and serves as a distributer for the control wiring, piping, etc., and as a means of access between the control building and the several unit bays. The main operating portion of the station is concentrated on the second floor, where are located the oil switches with their "disconnects" and the control room. There is little or nothing on the third floor which demands operating attention.

The ground floor contains current and potential transformers and feeder disconnecting switches which require attention or manipulation but seldom. Under each of the unit bays is a subway for distribution of cables. This connects at each end with longitudinal subways.

Starting from the control room, the first two bays are intended to provide for the receiving and distribution of power from station No. 3, Hydraulic plant. The other three bays are primarily for the distribution of power from the three new units, and into each of two of these bays is also connected an overhead circuit from the Niagara plant over which the flow of power is likely to be in either direction.

A radical departure from the usual station construction is the placing of all oil circuit breakers on the outside of the building walls; in other words, the main bus and switch structure walls are utilized as the walls of the building, all high-tension connections being upon the inside, where they are thoroughly housed and protected against the elements, and the oil switches upon the outside, where explosions and oil fires can do a minimum of damage. Galleries are provided on the outside for access to the oil switches, which are protected from the weather by suitable housings.

As this station is a very important one in the system, serving, as it does, as the general point of concentration for the output of the five contributing generating stations aggregating 400,000 hp. in capacity, great care was taken in its design to minimize to the greatest possible extent the hazards inherent in the operation of such a station. To this end the different electrical elements of the structure are separated and isolated to the greatest possible extent. In the first place, each unit bay is a separate building, as is also the control building. On the outside of the unit bays the oil switches are on one floor, the bus on another. On the inside the disconnecting switches for isolating oil switches are on one floor and the potheads for outgoing cable feeders are on another. The main and reserve buses are completely isolated from each other. Wherever the connections pass through walls or floors substantial porcelain bushings are used, sealed with cement compound so that there is no possibility of an arc being carried through the walls or from floor to floor. All phase connections are separated by brick and concrete barriers and are completely covered by compartment doors except where ventilation outlets are provided, so that accidental contact is virtually impossible.

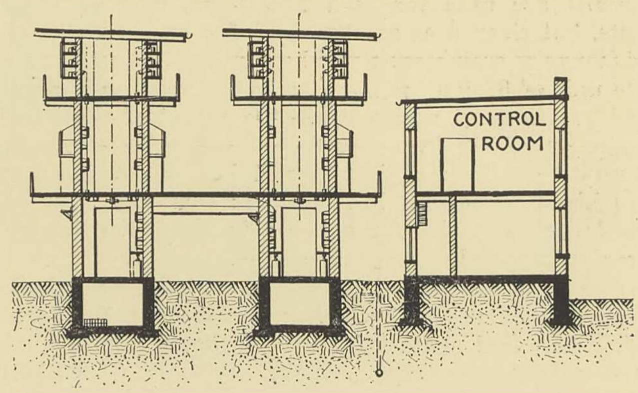


FIG. 57—LONGITUDINAL SECTION OF ECHOTA SUBSTATION, SHOWING TWO BAYS AND CONTROL ROOM

Arrangement of Circuits.—Each incoming line, consisting of two parallel circuits, passes first through disconnecting switches, after which the two circuits are combined into one and pass through a set of choke coils for lightning protection. The "disconnects" and choke coils are installed on the third floor of the connecting passageway in brick compartments. The lightning arresters, which are connected immediately outside of the disconnecting switches, are on the roof of the passage.

After leaving the choke coils the leads enter two 1,250,000-circ.-mil lead-covered cables in parallel which pass down the outer wall of the passage to the subway, thence across and up to the first floor of the unit bay. Here they emerge from the cables through potheads and connect to copper bars, which then pass through current transformers. Immediately above the current transformers are disconnecting switches above which the circuit divides, one side going through an oil circuit breaker to the main bus, the other side through a similar breaker to the unit reserve bus. In each bay provision is made for six outgoing feeders. Each of these connects to the main bus through an oil circuit breaker and to the reserve bus through disconnecting switches. The function of the reserve bus is twofold—(1) it serves as a true reserve bus from which all feeders can be supplied temporarily through the reserve-bus switch in case it is desired to clear the main bus for any purpose; (2) the reserve-bus switch serves as a substitute switch for any individual feeder switch which may be out of service. In this manner duplication of the switching facilities is obtained without duplication of oil switches on each feeder. Provision is made for the installation of reactors between bays and these will be installed as soon as they are required.

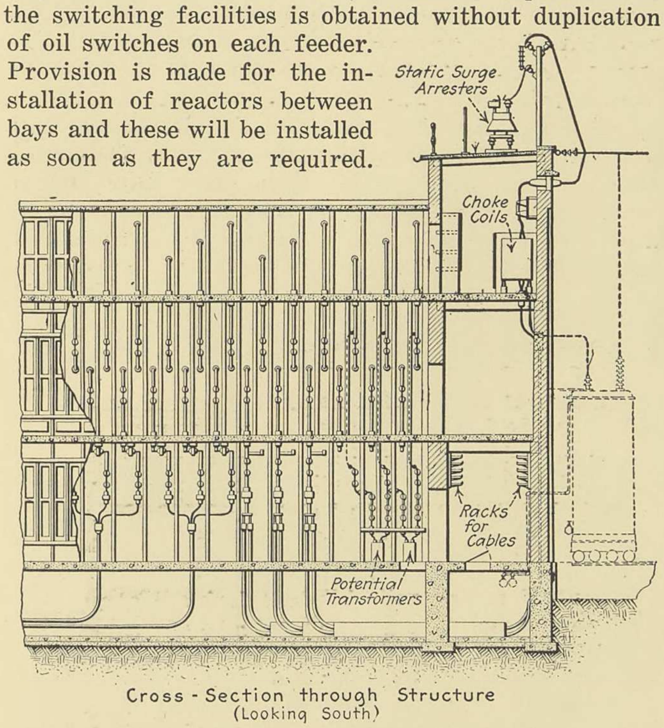


FIG. 58—TRANSVERSE SECTION OF ONE END OF ECHOTA SUBSTATION

Oil Switches.—Owing to the great importance of this station in the general scheme of distribution, both present and future, it was determined to insure the greatest possible degree of reliability in the oil switches. Accordingly both of the chief manufacturers were asked for a recommendation on this basis, resulting in the proposal of two radically different types of oil switches, namely, the Westinghouse type CO-2 and the General Electric type H-9. Owing to the absence of operating experience with these switches, it was found impossible to establish definitely the superiority of either one over the other, and it was decided so to construct the station

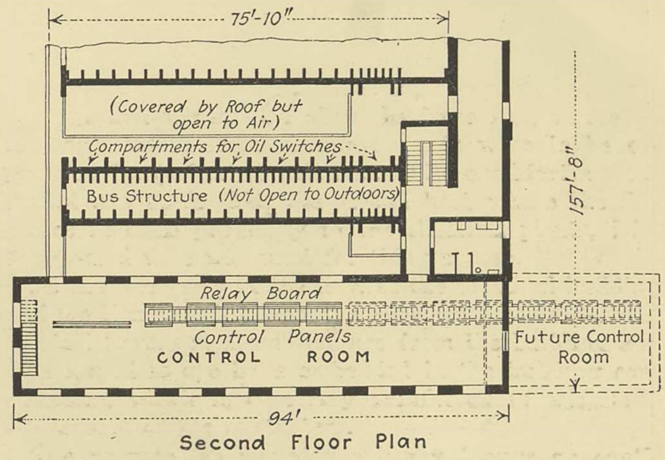


FIG. 59—PLAN OF CONTROL ROOM AND ONE BAY AT ECHOTA

that either one could be used. This was accomplished by slight modifications in the standard assembly of both types, and it was decided to install at the start a number of each type in order that actual operating experience might be had with both.

The General Electric switch is assembled with the oil pots staggered and all connections brought out at the back of the switch with center-to-center spacing of 9 ft. (2.7 m.) between adjacent switches.

In the case of the Westinghouse switches the same spacing of terminals was accomplished by a special design spreading the leads apart above the oil pots before passing through the wall. Thus an arrangement was arrived at whereby both of these radically different types of circuit breaker could be installed in the same width with the terminals equally spaced, so that either type of switch can in future be substituted for the other, should the type installed prove inadequate. Of the five bays, four are equipped with Westinghouse type CO-2 circuit breakers and one with General Electric type H-9.

Safety Features.—Objection has sometimes been made to this type of construction—in which the oil switches and their corresponding "disconnects" are placed upon opposite sides of a solid wall—that it is possible for the operator to open the wrong "disconnects" by mistake. This error may occur in two ways—either he may select the wrong group of "disconnects" or he may accidently get one "disconnect" on an adjacent oil switch. In this installation both of these errors have been made impossible by the following means:

First, the doors covering the disconnecting switches are all hinged at one side and all six doors associated with each oil switch are fastened together by a wooden bar which is hinged to their free edges. Thus, when it is desired to obtain access to the "disconnects" associated with a circuit breaker, all of the six doors are operated together. It is therefore impossible for an operator to obtain access to a "disconnect" of an adjacent circuit breaker.

Second, there is attached to each circuit breaker a shaft extending through the building wall carrying on its inside end a short cross-bar. When this bar is in a horizontal position it engages the edge of one of the disconnecting-switch compartment doors in such a way that the group of doors cannot be opened. This device is so connected to the oil-switch mechanism that it occupies this position when the oil switch is closed.

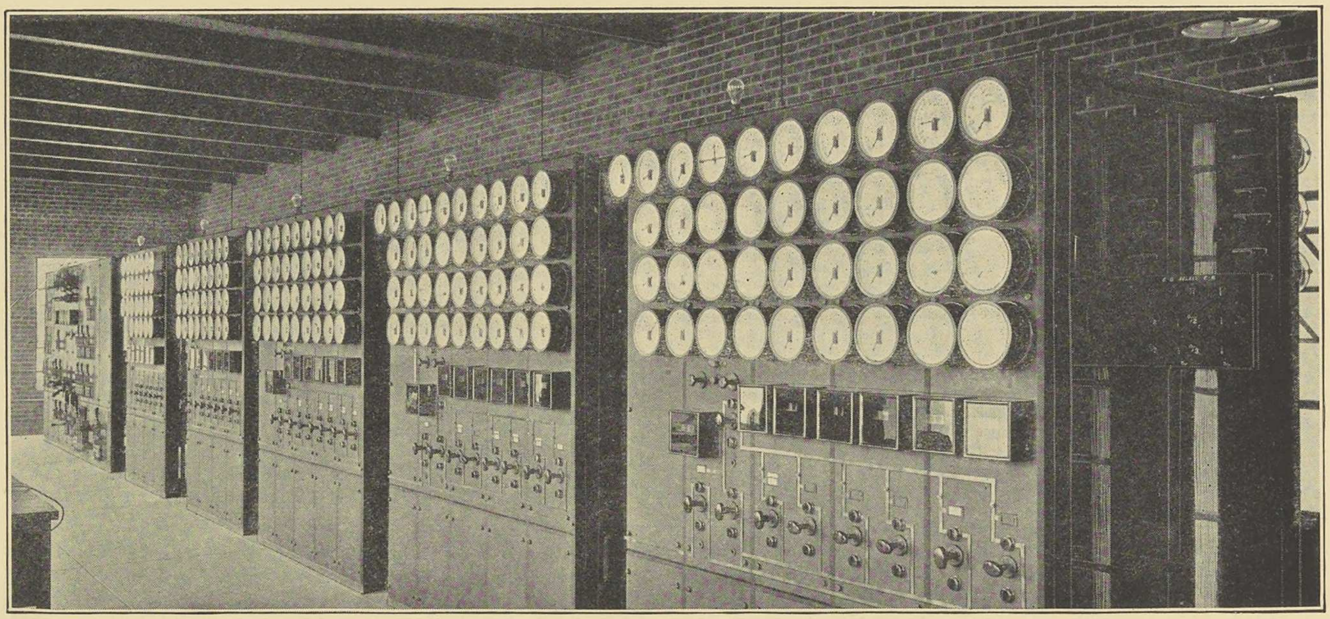


FIG. 60—GROUPING OF INSTRUMENTS AND ANNUNCIATORS ARE FEATURES OF CONTROL BOARD AT ECHOTA SUBSTATION

The instruments are arranged so that confusion in reading will be avoided. At the top of the board are the instruments and below are annunciators which indicate which relays have acted when switches open automatically.

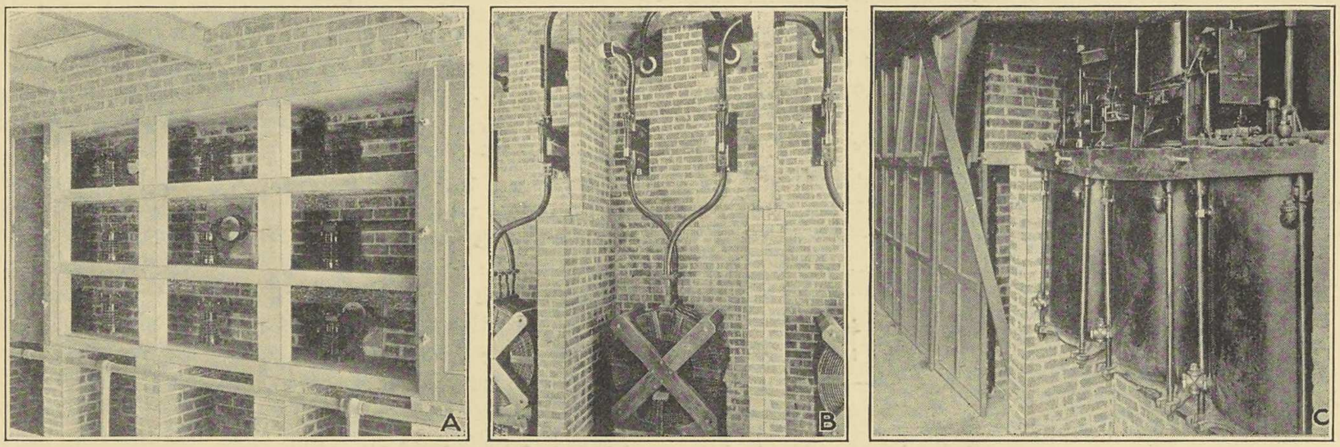


FIG. 61—A—TYPICAL SECTION OF A BUS COMPARTMENT. B—CHOKE COILS IN SERIES WITH INCOMING LINES AT ECHOTA SUBSTATION. C—ONE TYPE OF CIRCUIT BREAKER EMPLOYED AT ECHOTA

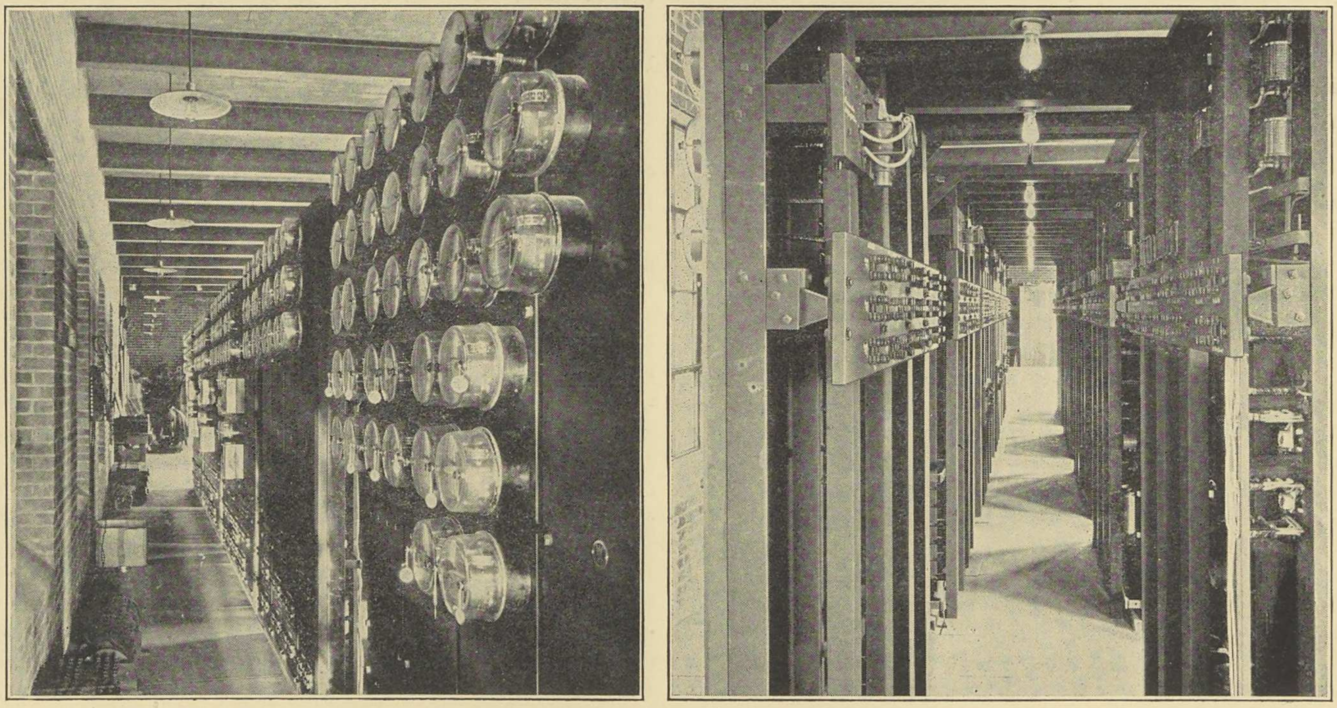


FIG. 62—BACK TO BACK WITH THE CONTROL BOARD SHOWN AT TOP ARE THE RELAY PANELS ILLUSTRATED AT LEFT

In the aisle between the control and relay boards are control-wire troughs and test terminals. Normally the troughs are covered, but one is shown open.

Upon the oil switch being opened the shaft is turned through an angle of 90 deg., so that the crossbar assumes a vertical position, which releases the disconnecting-switch compartment doors. Thus it is impossible for the operator to gain access to the disconnecting switches until the oil switch is in the open position. Provision is made for removing the crossbar by means of a special tool in case it is necessary for some special reason to gain access to the "disconnects" while the oil switch is closed.

On the reserve-bus side of the disconnecting switch alley, where there are no oil switches, there is, of course, no opportunity to employ this interlocking scheme; but the six corresponding doors are fastened together in the same manner as on the main-bus side. The same scheme of operating the doors in groups is also employed on the lower floor for the compartment doors, giving access to the feeder "disconnects," current transformers and cable potheads.

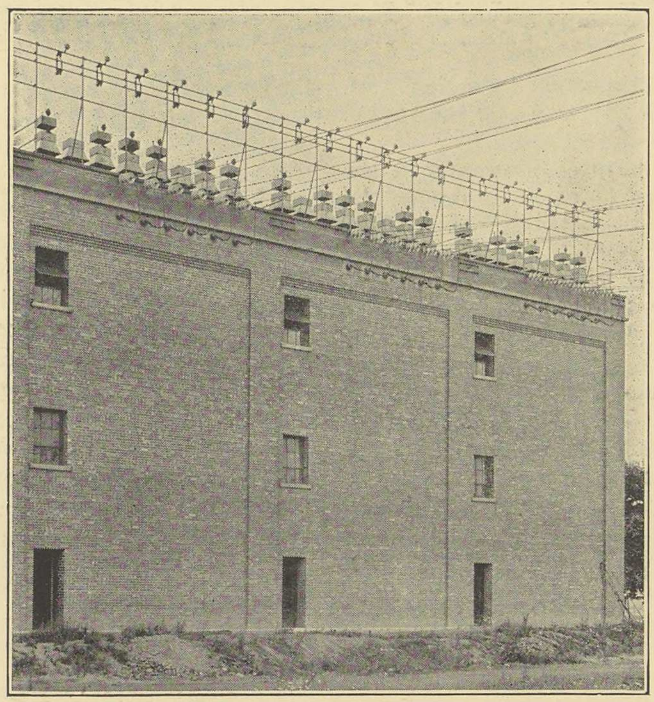


FIG. 63—OXIDE-FILM LIGHTNING ARRESTERS ON INCOMING LINES AT ECHOTA SUBSTATION

Control.—As shown by the illustrations, the control building is placed at one end of the series of unit bays and parallel to them. On the lower or ground floor are a small office, an entrance hall, a workshop or store room, a storage-battery room and a motor-generator room, also a longitudinal passageway for control wiring. The second floor is entirely occupied by the control room. The switchboards consist of vertical panels of natural-finished black "Linstun" and are divided into five sections corresponding with the five main bays, in addition to a house-service section. Back to back with the control boards, with a 4-ft. (1.2-m.) aisle between them, are the relay and terminal boards. A group of five panels controls each of the three bays connected with the new units—a bus-tie panel, an incoming-line panel and three fender panels, each controlling two feeders. A similar group of four panels controls each of the other two bays. A dummy bus indicates the connections. The bus-tie panel is equipped with three ammeters, a wattmeter and a reserve-bus voltmeter; the incoming-line with three ammeters, a wattmeter, power-factor meter, main-bus voltmeter, line voltmeter and synchroscope. Each of the feeders is equipped with three ammeters and a wattmeter. Each instrument and relay is provided with a complete set of calibrating link terminals mounted upon small panels on the rear of the main panels.

The vertical wiring on the back of the switchboards is carried in troughs made up of two $\frac{3}{4}$-in. (1.9-cm.) angle sides with "Linabestos" back, the troughs being $3\frac{1}{2}$ in. (8.9-cm.) wide. After the wiring was completed these troughs were equipped with removable sheet-metal covers. The advantages of this system of wiring are safety, accessibility, neatness, ease of installation and flexibility. Furthermore, the wires being entirely free from the panels, the latter can be easily removed, if required, by merely disconnecting the wires from the instruments and control devices.

At their point of departure from the board, all control wires pass through terminal links on the lower panels of the relay boards. After leaving the switchboard the control wires are carried in three-conductor cables covered with flame-proof braid and laid in steel pans or troughs mounted one above another on brackets fastened to the wall of the building. Upon reaching the point where the unit bays join the longitudinal passageway the pan for each unit passes through an opening in the wall of the passageway and continues along the outside wall of the bay under the oil-switch gallery. From this pan to the current and potential transformers, oil-switch controls, etc., the control wires are carried in conduit buried in the walls and floors of the structure. By this construction the control wiring is made accessible throughout its entire length, with the exception of the short portion in conduit, and at the same time an enormous amount of conduit work is avoided. The construction is much less expensive and occupies much less space than would the conduit necessary to convey an equal number of wires. For the operation of the control circuits there are provided two 14-kw. motor-generator sets and a 120-amp.-hr., 220-volt storage battery. The control is normally carried on one of the motor-generator sets and the battery held as a reserve.

Relay Protection—The incoming lines from the new generating station are each equipped with overload, ground and reverse-power relays. The overload relays are arranged to trip both the main and reserve-bus circuit breakers, but the reverse-power relays trip only the main-bus switch. At present the reverse-power relays are Westinghouse type CR, but it is proposed to substitute for these type CW relays so connected as to operate on low power factor, lagging current feeding from the substation toward the generating station. This is for the purpose of tripping the line switch in case of the accidental loss of the field of the generator and also to enable the line switch to trip on less than full-load current in the reverse direction. The bus-tie switch is equipped with overload relays. Feeder switches are relayed in two different ways, according to the nature of the feeder supplied. In certain cases where a feeder consists of four parallel cables split-conductor protection is provided between the two pairs of cables by means of suitably connected current transformers and low-current relays. In other cases ground relays are installed, connected in the current-transformer neutrals. Overload relays are also installed on all feed-

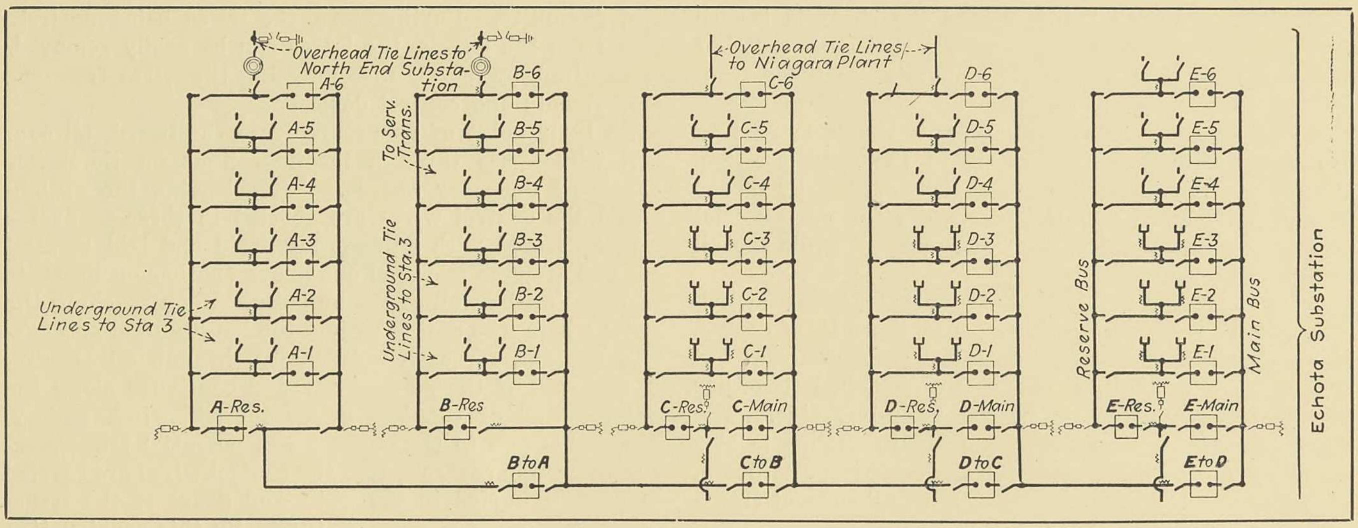


FIG. 64—SCHEME OF CONNECTIONS AT ECHOTA SUBSTATION, SHOWING UNIT LAYOUT
Lines from station No. 3 ext. are shown at the bottom. In these circuits but not shown in illustration are choke coils, lightning arresters and disconnecting switches.

ers. All relays are of the Westinghouse induction type, the 5-amp. size being used for overload and the 1-amp. size for differential and ground protection.

A somewhat unusual feature in connection with the relay system is the installation of annunciators on the switchboard with the drops connected in series with the tripping circuits of the various relays. By this means it is possible to know at once upon the tripping out of a circuit breaker just which relay was responsible. This immediately gives an indication of the nature and in certain cases of the location of the trouble. It also furnishes the means of keeping tabs on the operation of the relays. Although the station has been in operation only a few months, the value of this feature has already been amply demonstrated.

In the equipment of this station the Westinghouse Electric & Manufacturing Company furnished all of the switchboards and all of the oil switches with the exception of those for one unit bay, also current and potential transformers, choke coils, motor-generator sets and storage battery. The General Electric Company furnished oil switches for one bay and the lightning arresters. Bus supports and disconnecting switches are of the "Franklin" design manufactured by the Electrical Development & Machine Company.

The design and construction of this development were undertaken and largely carried out under the stress of war conditions. The design was in many instances influenced by these conditions, and many possible refinements were doubtless omitted owing to lack of time and men to carry them out. In spite of these conditions the results have been satisfactory as witnessed by some months of entirely successful operation.