37,500 K.V.A. FLOATING POWER PLANT

by

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April 22, 1947
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PROFESSOR J. S. NEWELL
Secretary of the Faculty
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Dear Sir:

In partial fulfillment of the requirements for the degree of Bachelor of Science in Mechanical Engineering, I am hereby submitting a thesis entitled "37,500 K.V.A. Floating Power Plant."

Respectfully,

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INTRODUCTION

In mid 1942, plans were being made by Gielow Naval Architects relative to the construction of four floating power plants for the U. S. Government. The idea sprang from the utilization of a U. S. Navy Battleship (the South Dakota) in supplying a large West Coast city with electric power fifteen years ago during an emergency shut-down of the central power plants in that area.

It is the purpose of this paper to explain the mission of these floating plants, to describe the major items of equipment aboard, to present the operating difficulties encountered, to show their performance by means of Thermodynamic Calculations, and finally, to mention the feasibility of post war operation for this type of power plant.

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MISSION

World War II was quite the antithesis of being a decided issue, as the idea of constructing central power plants that floated was being formulated. This country was very much in danger of suffering enemy air or sea attacks, a fact attested by the East Coast black out during this period. Should our large central power plants have been shelled or bombed, Industry (so vital to the national effort of all out war) would necessarily be slowed down in production. It was felt that insurance of a physical nature was advisable. This insurance was to be the floating power plant, which could be quickly towed to the scene of the bombing or shelling, tied to the transmission line, and operated until the damage was repaired.

The proponents of the plan had another reason why construction of the plants should be effected, though perhaps less well founded than the first. In the event of uncontrolled floodwaters on the country's large rivers, it was conceivable that central power stations, located on the river banks to utilize the river water to cool the condensers, might be inundated with consequent shut-down. These then, were the two selling points used to justify the plan-(Coastal Protection and Flood Control).

With the proposal adopted, that the experiment would be wise in the interest of National Defense, it had to be decided how many of these plants it would be advisable to make and what capacity output they should be. Even though this project was admittedly an experiment, obviously one plant would not be enough. One plant might be in service, while another central station was bombed. It would necessitate deciding which section of the country was in greater need of the power, while the other would have to go without. At the same time, nevertheless, the Government did not wish to spend too much money on a purely defensive project of this nature. For the development of other war experiments more on the offensive side was receiving the bulk of monetary appropriations. The rated output of the plants was also a factor to be taken into account to make a decision acceptable to the budget. It was resolved that aboard each plant should be installed the machinery to produce a 37,500 K.V.A. output, (sufficient power per plant to supply a city of 100,000 population). A cost analysis placed $4,000,000 as the figure on which to base the expense. Consideration for these strategic and economic factors resulted in the decision that four such plants should be built. Gielow Engineers, of New York, then commenced the drafting board design of the salient items of equipment to be installed. The contract was given to the Bethlehem Steel Company to make four cheap, flat-bottom hulls, devoid of means of self-propulsion, as the base upon which the power machinery was to rest.

The first plant - The INDUCTANCE - was completed in the spring of 1943; two more plants - the RESISTANCE and the SEAPOWER - were also launched toward the close of that year. The IMPEDANCE, the last of these craft, was not ready for operation until the summer of 1944. The hulls were towed to Pittsburgh, where the power machinery was installed by the United Engineers Construction Company, situated on the Monongahela River. Civil Service personnel observed the assembly, and it was they who conducted the preliminary tests on each of the plants as it became ready. The Defense Plant Corporation acted as the agency of the U.S.Government on these plants, as extensive operating tests were made in Pittsburgh and Memphis.

With the establishment of the fact that the floating power plant was a sound engineering endeavor, developments in Europe were such that bombings or shellings from enemy forces on our coastal cities were extremely unlikely. For, toward the end of 1943, Italy had surrendered and the Allies had control of North Africa and Sicily. The threat of German air power had been repulsed after the Battle of Britain and German Naval action was limited largely to lone submarine raiders. In fact, large R.A.F. and U.S. air raids were becoming daily occurrences in Nazi occupied sectors of Europe. Thus the passage of events had direct effect upon the mission, as well as the design, of the floating power plants. The Government had appropriated $16,000,000 for this experiment and had realized nothing in return, up to this point, except the satisfaction that they would produce electrical energy. It was realized, at this time, that their being desirable in the event of floods was but a selling point.

Agents of the Government could find but one public utility company that would contract to lease the use of one of the plants for full time power production. The boilers in the floating power plants are constructed to burn oil or natural gas. The utility company in Pensacola, Florida, having access to an abundant supply of gas, arranged to have the use for a period of one year of the INDUCTANCE, the first plant built.

But there were two more four million dollar plants standing idle, and a third in the process of construction. The original proponent of the whole scheme--the Office of the Chief of Engineers--was smarting as the result of the non utility of so much invested capital. Shortly, however, was to be forthcoming, another "selling Point" or "raison d'être." At this period (the latter part of 1943) the big military speculation by second guessers was when and where was the second front to be established. There was no doubt but that our concentration of U.S. forces in England was preparing for an invasion of Hitler's Fortress Europe. Obviously, a beach-head would have to be established, whether the invasion occurred in southern France, Brittany, Normandy, Belgium, or even Norway. The tenacity with which an invading force holds a beach-head and the speed at which it moves inland once it consolidates its units are dependent upon its supply lines. The German Army was naturally expected to demolish all harbor facilities (those that were still in operation after the softening up of the enemy by Allied bombing) while being pushed back. Power plants would be one of the most certain objects to be demolished by retreating forces, even if they had no time for more extensive scorched earth policy.

Groping around to find some way to justify the appropriation of $16,000,000 taken from War Bond purchases and taxes, the proponents hit on the scheme to send the floating power plants to Europe so that they could supply the power to run the innumerable electric cranes, the sluices, and other harbor facilities. In this manner was some measure of face salvaged, though there cropped up other problems to be solved. The floating power plants were designed for producing electrical energy at sixty cycles per second, but all of Europe was fitted out with motors and other electrical appliances designed for fifty cycle operation. Secondly, how was a 6000 ton flat bottom scow to be propelled across the Atlantic Ocean? Thirdly, the plants were equipped with but one water evaporator, which was designed for fresh water evaporation; the plants would no doubt operate in a harbor and be evaporating salt water. With increased evaporator blowdown being necessary, the plants might be unable to get along at continued full load operation with only one raw water evaporator.

The question, at this point, that was debated was whether more taxpayers' money should be used to re-outfit the ships for foreign operation, or let them rust in inutility on the river in this country, while hoping some company would contract for their use in order to salvage a little something from the experiment. The former plan was adopted, though the time factor did enter herein; for invasion was imminent and the power plants should be ready in England to be transported to the scene of the landings in order to achieve their newly created mission. First the SEAPOWER and then the RESISTANCE were sent to New Orleans, where the reconversion jobs were accomplished. An extra fifty feet were added to the length of the barges in the form of a blunt prow containing a forward crew's quarters and ballast tanks. As originally constructed, the floating power plants were square at either end (the plan view was a rectangle), so it was hoped that a prow would result in less pounding of the flat bottom barge. The hulls were designed for inland and coastal water ways only, not for continuous beating of the angry seas in mid ocean; but it was expected the plants would successfully make the crossing. The turbine was rebladed and supplied with a 50 cycle governor in addition to its original 60 cycle governor, so that it then could be operated at either frequency, as the occasion might dictate. Since the station auxiliaries were 60 cycle operated, a frequency changer set (50 cycle synchronous motor driving on the same shaft a 60 cycle generator) was installed. To provide for additional make-up capacity, a second raw water evaporator was put aboard. A galley was provided at the aft end of the vessel, with additional sleeping quarters also aft. Naturally, U.S.Army personnel would operate the plants in the foreign theaters of operation.

In April 1944, an army crew commenced its training in Pittsburgh on the SEAPOWER, the only plant, at that time, the conversion of which, was complete. It was at this point that the author first entered the picture, earmarked to be a member of the crew of the second ship to be converted - the RESISTANCE - . He was sent on temporary duty for six weeks aboard the SEAPOWER to observe the training of that unit. Activation of the second army crew (that of which the author was a member for 21 months) followed. This unit was designated the 1717 Engineer Floating Power Plant. Eight weeks of basic training in Camp Claiborne, Louisiana were succeeded by eight weeks of technical training aboard the INDUCTANCE at Pensacola, while awaiting the completion of the conversion of the RESISTANCE for overseas passage.

The two plants were to be towed by an ocean going tug to Europe with a skeleton crew aboard each barge. In view of the weak structure of the hull and unorthodox lines of the barge, it was not considered safe to put the full crew aboard during the voyage. In addition, the trip was bound to be so slow that sufficient refrigerator space was not available for food for a full complement of men. October 18, 1944, found the two plants, RESISTANCE AND SEAPOWER, headed on their journey from New Orleans to Europe. A skeleton crew of twelve army personnel was aboard the SEAPOWER; the author was one of fifteen aboard the RESISTANCE. In addition, maritime rules decreed that four merchant mates be aboard, though their actual utility was nil. The skeleton crew was needed to put the turbine on turning gear periodically and to keep proper mild alkaline concentration in the boilers, which were in wet storage.

The means of motivation, as previously indicated was a seagoing tug with two six cylinder diesel engines capable of developing 1150 horsepower each. The two floating power plants were part of a queer looking convoy composed of 22 ships, including 50 ton diesel operated floating cranes, small "Y" type oil tankers and U.S.Navy destroyer escorts for protection. This slow moving convoy traveled, on the average, at a rate of four knots. The trip consumed a total of 51 days, from the time the crew stepped aboard until it stepped ashore in Antwerp, Belgium. At the time of the arrival of these plants in Europe, in late 1944, Cherbourg was the port that was supplying the U.S. and British forces, with some help from LeHavre. The Red Ball highway (the route of U.S. Quartermaster supply trucks' travel from the port to the front) was stretching ever longer. Newly liberated Antwerp, then, which was but a few miles from the front, was a more logical port in which to operate the plants. Rather than keep them both together, though, the SEAPOWER was turned around, and went back out to the North Sea and thence to Ghent, Belgium. This was the period at the beginning of Von Rundstedt's counter-offensive in the Battle of the Bulge.

Antwerp was not to be the actual area in which the RESISTANCE was to operate; rather, a small town, Schelle, was selected in which is located the largest power station in Belgium. As soon as the remaining 44 men of the crew caught up with the RESISTANCE, operation of the floating power plant commenced on the Scheldt (L'ESCAUT) River at Schelle. The large central station, alongside which the RESISTANCE was moored, has three 30,000 K.W. turbo-generators and one 60,000 K.W., for a total rated capacity of 150,000 K.W. At this time, though, the station was only producing energy at a rate of 25,000 K.W. The large turbine and one of the smaller ones were inoperative as a result of damage in certain of their stages, and were being repaired but slowly. The engineers at the Belgian Plant (the name of which is INTERESCAUT) maintained that Belgian patriots inserted explosive charges as a means of sabotage while the Germans were still occupying the area. In addition, coal in the winter of 1944-1945, was an extremely scarce item, since the coal mines were in the process of being liberated, and the Belgian workers were striking to get more pay, for the iron German hand, was no longer holding them in subjugation. These facts coupled with the fact that the floating power plants burned oil, finally gave a "raison d'être" that was tangible. For our production of Electric Power could easily be translated in terms of Lend Lease to Belgium.

The two plants in Belgium generated at the rate of about 25,000 K.W. on the average, though each did hit peaks of 30,000 K.W. for a day or two, steadily, at a time, all the while generating at 50 cycle frequency. According to the VOLKSGAZET (an Antwerp newspaper), the two U.S.Army floating power plants produced 18% of the electrical power produced in all of Belgium during the month of March 1945. During this month, representatives from Holland came to the RESISTANCE, relative to moving it to Rotterdam in order to produce power for the Netherlands. Since, however, there is a connection between the power lines of Belgium and Holland, both countries agreed that it would be well for the plant to remain at Antwerp and send 15,000 K.W. to Holland. The RESISTANCE operated at Schelle until late July 1945; during this time, it generated 81,289,000 K.W.-Hrs. net output. This generation represented a saving of about 65,000 tons of coal, which were thus directed to other use. The SEAPOWER ceased operation toward the end of June 1945, having delivered to the

COAL CONVEYORS & BUNKERS @ INTERESCAUT

POWER LINES FROM RESISTANCE TO INTERESCAUT

Belgian and Dutch grid systems, a net of 72,000,000 kilowatt hours.

At about the time the floating power plants in Europe were concluding their missions, the fourth plant - IMPEDANCE - commenced its journey from New Orleans to Manila. To save time, the only conversion on this plant was to fit it for 50 cycle generation and to install the additional raw water evaporator. The IMPEDANCE, therefore, made its Pacific voyage with no prow, but only a square bow to pound the waves. Redeployment to the Pacific theater before the termination of hostilities on 14 August 1945, resulted in half the crew of the SEAPOWER being assigned to operate the IMPEDANCE, for there was a scarcity of trained Army operators for a third crew. The IMPEDANCE commenced generating in the fall of 1945, in Manila.

The narrative, at this point, has reached the conclusion of the war time employment of the floating power plant, two of them having been sent to Belgium, a third to Manila, and the fourth operating in the United States. It has been attempted to point out the missions of these plants from their inception. Economic and strategic considerations were shown to be determining factors in the employment of the plants. The original mission of the floating power houses was for home defense, while the enemy countries held the military advantage over the U.S. Changing military conditions finally resulted in the floaters being a part of U.S. Lend Lease to Allied Countries. Finally, like all other U.S.Army surplus property, their disposal, after the cessation of hostilities, became a problem.

GENERAL DESCRIPTION

The floating power plant is just what its name implies - a power station mounted on a steel hull in order to provide mobility for it. This hull is of 3/8" steel, is 358 feet long, and is 50 feet in beam. The entire bottom portion of the barge consists of oil, fresh water, and ballast tanks, which when loaded to 95% capacity (the optimum loading for overseas travel) results in a displacement of 6000 tons. This loading for overseas movement is selected to have the plant draw 12 feet of water at the aft end, with a 3½ foot drag. The fuel oil tanks are of three types; double bottom deep tanks, and settling tanks, all of which are provided with steam coils to permit heating of the oil to facilitate fuel oil transfer. When full, these fuel oil tanks can hold a total of 567,600 U.S. gallons. In addition, a diesel oil tank of 18,800 U.S. gallon capacity is provided. Two portable water tanks aft hold a total of 54,600 gallons; while two aft ballast tanks are of 74,000 gallons total capacity, and two forward ballast tanks can hold 38,900 gallons of raw water.

The barge is fitted out with four 4-ton anchors, two forward and two aft. All these anchors were entirely necessary, in addition to steel cables and 9 inch rope lines, to hold the vessel in the strong current of the Scheldt river, which has a 20 foot tide. An electric driven capstan serves to raise each anchor, as well as to provide a winch to take in lines. Three hundred feet of anchor chain is attached to each of the anchors. There are two 30 man life-boats on the top deck, together with two life rafts. A small 50 K.W. Cummins Diesel has been installed on the top deck to produce the small amount of auxiliary power needed aboard in transit. Before embarkation, the vessel was depermed at the Naval Station in New Orleans. A degaussing coil completely girdles the barge, and a compensating coil is provided for the ship's compass. Degaussing merely amounts to sending a direct current through the coil to produce, by means of a certain number of ampere turns, a magnetic flux just sufficient to offset the natural flux generated by the steel hull, which if not neutralized would set off magnetic mines. Degaussing was necessary only in waters less than 300 feet in depth; a small motor generator set provided the D.C. current for the degaussing and compensating coils.

Before describing the main power plant machinery, the narrative will first examine the vessel as a whole from stem to stern. There are three decks on the plant; these will be frequently be referred to. The lowest deck is the tank top level, which is 3'6" above the base line; this deck is the top of the double bottom fuel oil tanks. The next higher deck is called the main deck; the turbine, generator, switchboard and tops of the deep tanks are at this level. Finally, there is the top, or weather deck upon which are mounted the life - boats and other deck gear. Reference may be made to Fig. 1 in connection with the description that follows.

A port and a starboard ballast tank are located in the foremost portion of the prow. There is a paint locker on the tank top of these ballast tanks. Just aft of this paint locker are situated the two chain lockers, one on either side, with the capstan machinery in between these chain compartments. Next to the rear is the forward crew's quarters, capable of housing 26 men, and a sick bay with space for four occupants. A head with two showers is also a part of the crew's quarters forward, all of which are directly above deep fuel oil tanks. Squeezed in just aft of the crew's quarters, is a forward ammunition locker.

The cooling water intake system is the next thing encountered, progressing toward the aft end. There are two rectangular openings on each side of the ship (the photograph shows these openings quite clearly) through which raw water is drawn, as the medium for cooling in the main condensers. The waters drawn from the two sides of the vessel enter a common waterway at the center of the barge, where a large chainfall operated sluice gate is installed. Passing through this sluice gate, the water enters a large chamber known as the screen well. Three motor driven Rex traveling screens are side by side in the screen well in order to filter the raw water. A continuous backwash of water from the raw water pumps washes seaweed and other foreign matter off the fine mesh copper screens into a trash trough, which discharges over-board on either side. Two mud eductors are placed in the outlet side of the traveling screens to suck the mud off the bottom of the screen well. The kinetic energy of the jets is produced by 40 psi.g. raw water. These eductors also discharge on either side of the plant. On each side of the vessel are two large

INLET TO RAW WATER SYSTEM

EGRESS FROM WATER DUCTS

manually operated gate valves that send the cooling water to its next destination - two 42 inch ducts. These ducts, one on either side, run the length of the ship. A Wallace and Tiernan water chlorinator permits injection of a chlorine solution into either duct just aft of the two gate valves to get rid of algae that may collect as a result of organisms in the raw water. These 42" ducts serve to carry the raw water to the circulating pumps, to the condensers, and finally discharge out the aft end above the water line.

Just aft of the screen well is the next major compartment - the transformer well -;from the tank top (3'6" level) to the top deck extends the main plant transformer. Sandwiched in around the screen well and the transformer well are a carpenter shop, chlorination room, store room and battery room (containing the ship's storage batteries and small items of electrical equipment). On the port side, between the transformer well and the outside of the vessel, is located a boatswain's store room on the tank top, and on the main deck level is the main oil circuit breaker and equipment for phasing out (to get the ship's electricity in phase with that of the utility ashore). At the tank top level, on the starboard side, between the transformer well and the side of the vessel, is a space devoted to the storage of machine shop supplies and replacement parts. Incidentally, the chlorine solutions are injected into the 42" ducts, where they pass through this machine shop storage space and through the "bosun's" storeroom (on the port side). Above the former compartment, on the main deck level, there is a machine shop. This shop contains a fourteen inch standard engine lathe with an 8 foot bed, a 24" Gould & Eberhard Shaper, a 14" Racine power hack saw, a number 2 Cincinnati milling machine, and a 6 x 32 cylindrical grinder. In the aft section of the machine shop store room is a tank where turbine lubricating oil is stored; suction may be drawn on this tank by the turbine lube oil pump to transfer this oil directly into the turbine oil reservoir.

Situated on the main deck level over deep fuel oil tanks and just aft of the transformer well is a large compartment termed the switch gear room. The air circuit breakers for the two main diesel generators, for the forced draft fans, boiler feed pumps and the bus tie are all to be found in this sector. There are two air cooled auxiliary transformers that step the voltage down from that produced by the main generator to the 440^V used in the station bus system. The degaussing generator and two small direct current generators (driven by alternating current motors) are also located in the switchgear room.

On the other side of the bulkhead, aft of the switchgear room is the pump room - the lower pump room being on the tank top and the upper pump room on the main deck level. In the middle of the lower pump room is the boiler feed pump pit, which extends down the 3½ feet to the bottom of the barge. The two electric driven and one steam turbine driven main boiler feed pumps are based here. Surrounding these large pumps, but on the tank top level, are many other items of equipment. The deep diesel oil tank lies between the deep oil tanks under the switchgear room and the forward bulkhead of the lower pump room.

As the two 42" ducts enter the lower pump room on either side, a ten inch header takes off each providing suction to the six raw water pumps in the forward portion of this room. One of these raw water pumps is designated a fire pump, for its discharge may go directly to the fire and sanitary systems; four of them are merely termed raw water pumps; and the sixth is a bilge pump, which can take its suction off the 10" header or the bilge line. The main function of this raw water line is to produce the cooling fluid for the two large fresh water coolers, which also are in the lower pump room. The fresh water cooled in these shell and tube heat exchangers serves to cool the lubricating oil of the turbine, to cool the oil in the main transformer, the cylinders in the diesel engines, the main hydrogen cooled generator, and a host of other items. Four fresh water pumps (exactly the same size and make as the raw water pumps) produce the pressure in this system, taking their suction from a 4 inch header coming from the portable water tanks aft. The heart of the fuel oil transfer system also lies in the lower pump room. Two rotex type fuel oil transfer pumps are the prime movers of the fuel oil. An air operated pneumercator system indicates, by mercury gages, the amount of liquid in all of the fuel oil, diesel oil, and water tanks, and most of the control valves are located in this area.

The upper pump room, likewise, contains myriads of equipment. At the bulkhead adjacent to the switchgear room stand two large diesel engines each driving a 300 K.W. generator. The function of these engines is to produce the power needed by the station auxiliaries to put the main unit into operation.

To produce 200 psi.g. air pressure needed to start the large diesels (for they are started as air motors) there is a 2 cylinder gasoline engine driven two stage air compressor. In addition, there are two 2 stage electric motor driven air compressors capable of producing 200 psi.g. air or 100 psi.g. air. The lower pressure air serves as the operating medium in the many automatic controls. Supported high in the upper pump room is a huge deaerator, with outlet to the boiler feed pumps below. On either side of the dearator on the main deck level stand the two raw water evaporators, to produce make up to the feedwater system. These evaporators are supplied with water from the raw water pumps which first passes through two heat exchangers - the evaporator feed heaters - before entering the main evaporators. The vapor generated in the evaporators is piped to the shell side of an exchanger known as the evaporator condenser through the tubes of which passes the boiler feedwater on its way to the deaerator. The last major items of equipment in the pump room to be noted are two contaminated evaporators, the function of which is to generate the steam used to heat the fuel oil in the various tanks by means of heating coils located in each of the oil tanks. The contaminated steam system is provided to be completely divorced from the main steam from the boilers lest any oil enter the lines through leaks and make its way into the boiler drums.

Aft of the pump room lie two more rooms, the turbine room on the main deck and the condenser room on the tank top. On the lower of these two levels are the two main condensers, one on each side of the ship. The raw water circulating pump of each condenser draws its suctions from the 42" raw water duct, and discharges directly into the tubes of the condenser; a continuation of the 42" duct takes off from the condenser discharge and continues aft for the rest of the length of the ship. For the condensate system, there exists a hotwell for each condenser and two condensate pumps drawing from each hotwell. In the center of this room (directly below the turbo-generator) is the main condensate storage tank, serving as a reservoir for condensate, and having a cooling tank adjacent to it. On the starboard side of the condenser room is a drip tank, which receives the gland steam leak off, the condensate from the traps on the boiler drains, the condensate from the emergency stop valve drain, and other such high and low pressure drip. On the port side of this room, there is the hydrogen seal oil system. This consists of the hydrogen seal oil detraining tank, the hydrogen seal oil pump, the vacuum pump, the hydrogen seal oil cooler, and the related valves and lines of the system.

The turbine room stands on the main deck just above the condensate room. Directly in the center is mounted the turbo-generator with its exciter and pilot exciter. At the forward bulkhead of this room are two hydrogen bottles and five carbon dioxide bottles all connected to the same system. The carbon dioxide purges the air prior to injection of hydrogen into the generator casing so that explosive concentrations of hydrogen in air will not exist; a percentage of hydrogen in air of from 5% to 75% is explosive. Likewise, when it is desired to remove the hydrogen from the generator, carbon dioxide is the purging medium. On the port side of the turbine, the switchboard is mounted upon a rubber foundation. This enclosure contains the hydrogen control panel, port and starboard feeder panel, a control panel for each diesel, the main generator, the frequency changer, and the turbine supervisory instruments (such as eccentricity recorder, vibration recorder, and tachometer). Wattmeters, overcurrent relays and a ground relay are located in the back of the switch board. Facing the steam inlet end of the turbine is a turbine control panel containing pressure gages, condenser vacuum gage, salinity indicators, and temperature gages. The oil operated emergency stop valve is on the main steam line just before it enters the turbine steam chest through the control valves. A two stage air ejector is provided on each side of the turbine room, one for each condenser. The frequency changer and the main generator field rheostat are both located starboard of the turbine. The turbine lube oil tank extends downward from the main deck level into the condenser room; in connection with this system, a DeLaval centrifuge is provided to remove water from the lubricating oil. A low pressure feed water heater receives condensate from the air ejectors; from the low pressure heater, this condensate proceeds out of the turbine room into the evaporator condenser which is in the upper pump room. The high pressure heater is also to be found in the turbine room (port side). It receives its water from the discharge line of the boiler feed pumps.

Progressing once again toward the aft end of the plant, brings one to the No. 2 boiler room and aft of this room, to the No. 1 boiler room. Each boiler occupies one separate room; they are identical except that they are mounted 180° relative to each other in order that the weight distribution may be compensated. The boiler foundation rests directly on the tank top; down there, also, is the boiler control panel, which contains the automatic combustion controls, in addition to temperature and pressure gages and flow meters. Upon the lower section also, is the forced draft fan, which takes its inlet air from out of the side of the ship as well as from the boiler room. High up, from the main deck to the top deck, is suspended the fuel oil settling tank. Oil is drawn off the bottom of this tank into the two fuel oil service pumps in the lower section of the boiler room, and circulated through three oil heaters before going to the burners. Contaminated steam, of course, supplies the heat to these exchangers, as well as to the settling tanks. There are two chemical feed pumps capable of producing 1500 psi. pressure and a chemical mixing tank located in lower boiler room No. 2. These small positive displacement pumps inject chemicals in solution into the steam drums, one pump for each boiler; they may also be used for hydrostatic tests of the boiler systems. A blowdown tank stands on the main deck in No. 2 boiler room; the blowdown lines from both boilers pass into this tank on their way overboard. These pieces of equipment are the important items that are not part of the boilers proper, but are located in the boiler rooms.

The donkey boiler room is on the tank top, aft of the No. 1 boiler room; this room derives its name from an oil fired heating boiler used to produce steam for the ship's galley and unit heaters. In addition, it ties into the contaminated steam line as an emergency measure. A small water testing laboratory has been set up in this room on the tank top, where the daily tests of feedwater, boiler water, and evaporator brine are accomplished.

Two cylindrical sand filters receive raw water from the fire line to produce filtered water for the ship's sanitary system and for cooling the bearings of the raw water circulating pumps. A storage tank in this room serves as a reservoir for diesel oil to supply the fuel for the donkey boiler. Finally, a quartermaster laundry has been installed in this compartment, consisting of a washer, centrifugal drier, and steam drier, all for the convenience of the ship's crew.

Above the donkey boiler room, on the level of the main deck, is the aft crew's quarters, consisting of four-man staterooms and an area of bunks in the open space, and a head. On this same level, extending to the rearmost portion of the ship, there are the following other rooms. On the starboard side is a divided refrigeration space for the ship's perishable food stores; a 2 ton (of refrigeration) meat box maintained at a temperature of 15° F is built right inside the 1 ton (of refrigeration) capacity vegetable room, kept at a 40° F temperature. Inside the vegetable room, an icemaker capable of making 30 pounds of ice in trays, provides ice cubes. Between the refrigeration spaces and the aft end of the vessel is found the refrigeration machinery room, housing two complete units (one used as a standby) each consisting of a belt driven freon-12 compressor. The refrigeration system contains a total of 140 pounds of freon-12 when filled to capacity. The pivot for the starboard rudder is also in this room. Directly behind the aft crew's quarter is a passage-way, in which are the aft capstans, a brig, one non-perishable food storeroom and the aft ammunition locker. Between these last compartments and the stern are the two aft chain lockers and the CO_2 room, which houses a bank of 76 bottles of CO_2 which can be directed to any of the machinery rooms by remote control in the event of fire in the machinery. Extra hydrogen and freon-12 bottles are stored here; the pivot for the port rudder, and the rudder machinery are also mounted in the CO_2 room. Beneath these rooms are the aft ballast tanks, extending down to the bottom of the boat. On the level of the mooring deck, above the aft crew's quarters and head, there is a galley, a mess hall, and additional staterooms. The relative positions of all these rooms and items can be seen by referring to fig. 1.

To this point, the description of the floating power plant has been general. It has been attempted merely to give an overall account of the physical make-up of the plant to portray the various facilities aboard. Before the technical details of the power plant machinery are given, a break-down of the ship's crew into its various categories is in order. Each army unit has a Table of Organization, which lists the ratings of the personnel assigned and the tasks of each individual. In command of an army floating power plant was a Major, supposed to be the possessor of a degree in both mechanical and electrical engineering. A Captain, designated the electrical engineer, was the executive officer and two first lieutenants, one an electrical engineer and the other a mechanical engineer, completed the officer component. The author held the position of mechanical engineer on the RESISTANCE. The operating personnel was divided into four shifts, each of which consisted of a powerhouse engineer or shift foreman (who was a master sergeant), a switchboard operator, a turbine operator, a pump room operator, and two boiler operators. One maintenance crew of machinists, steam fitter, and blacksmith was provided for, and another maintenance crew of electricians was aboard. The remainder of the crew was composed of a crew of deck hands and administrative and mess personnel. The table of Organization provided for a total of 59 men to operate the plant under full production.

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TECHNICAL DESCRIPTION

TURBO-GENERATOR

The full load rating of the turbine is 30,000 kilowatts, using steam at 815 psi. gage pressure and 900° F temperature; the turbine exhausts to 1.5 inches of Hg absolute. Built by the General Electric Company, the turbine operates at a speed of 3600 r.p.m. for 60 cycle operation. As previously noted, it has been rebladed for 50 cycle operation as well as the standard 60 cycles so that it can be used either in Europe, the United States or the Philippine Islands. At the lower frequency, the speed and out-put are 50/60 of that at the standard frequencies, resulting in 3000 r.p.m. and 25,000 K.W. for these items respectively. Steam enters the steam chest through ten controlling valves operated by cams driven through the medium of a rack, which receives its impulses from the hydraulic cylinder. Five of these valves are located on the top of the turbine and five below, for a symmetrical arrangement about the turbine steam chest. These control valves open progressively as the turbine is started, because of the arrangement of the cams, so that steam is admitted gradually. Fig. 2 is a longitudinal semi-section of the turbine, which is supplied by the manufacturer.

This 19 stage turbine is designed with four extraction stages, utilizing the sixth, ninth, thirteenth and sixteenth stages for this purpose. Three of these extraction points (the 9th, 13th and 16th) are provided for feed water heating and one for emergency use to drive the steam driven boiler feed pump. The pressures of these extraction points are naturally dependent upon the load the turbine is carrying, but at full load of 30,000 K.W.

sixth stage pressure is 275 psi.g, 9th is 170, 13th is 60 and the sixteenth is atmospheric pressure. An Atwood-Morill air operated valve is located in each of the steam extraction lines as it emerges from the turbine casing. Ninth stage extraction supplies the high pressure feedwater heater, contaminated evaporator, and the raw water evaporators; thirteenth stage, the deaerator; and sixteenth stage steam is used in the shell of the low pressure heater.

In the main superheated steam line, before it enters the steam chests of the turbine, is the oil operated emergency stop valve, with a steam strainer built into the head. The diagram of the turbine hydraulic control system (Fig. 3) shows exactly how this valve fits into the system. Oil pressure of 120 psi.g. is needed to force the valve stem upward against the coil spring; the stop valve is open with the stem rising. Normal hydraulic pressure produced by the twin turbine lubricating oil pumps is, however, 150 psi.g. The following safety features are included in the hydraulic line leading to this valve: A vacuum trip valve, a hand and solenoid trip valve, and an emergency automatic trip valve. Loss of vacuum in the condenser closes the vacuum trip valve so that oil pressure can not find its way to the hydraulic cylinder of the emergency stop valve. The hand trip valve is for periodical test of the stop valve to see that it is not stuck open while the turbine is being started, as well as when in normal operation. Over speeding of the turbine (to 4000 r.p.m.) serves to trip the emergency automatic trip valve so that it diverts its supply of oil to the drain instead of to the stop valve. With any of these devices tripped, then, steam can not be admitted to the turbine. If the situation is more than a monentary condition, steam pressure will build up in the boilers until the safety valves on the superheaters open.

Turbine lubrication is adequately provided for, with a lube oil reservoir situated at the front of the turbine under the main deck, extending down for a depth of eight feet. A vapor extractor takes a suction from the lubricating oil tank to remove the vapors from this closed vessel. Shaft mounted twin worm wheel oil pumps provide the normal lubricating oil pressure at 150 psi.g. The oil is used at this pressure in the hydraulic system for operating the emergency stop valve and as the operating medium in the main hydraulic operating cylinder of the turbine governor. For bearing lubrication of the turbine and generator, however, the oil pressure is reduced through a valve to 25 psi.g. Normal temperature of the oil returning from the bearings is 140° F; it is then cooled by means of a shell and tube heat exchanger down to 110° F. The cooling medium of this heat exchanger is fresh water, which is, itself, cooled in the lower pump room by the fresh water coolers.

The hydrogen seal oil system is closely linked with the lubricating oil system; replenishment of oil for the former system comes from the turbine lube oil tank, and in emergencies, the turbine oil pump can produce the oil pressure for the seal oil system. Oil forms the inner seal at the bearings of the generator to prevent hydrogen from escaping from the generator casing to the atmosphere (for the hydrogen pressure is maintained above atmospheric). The seal oil picks up some hydrogen and carries it on back to the hydrogen detraining tank, which is divided into three compartments (the air detraining section, hydrogen detraining section and the vacuum tank). A vacuum pump serves to produce a vacuum of 28 inches of mercury in the last named tank. After having entered the vacuum tank as a fine spray, the seal oil is drawn out the bottom to the hydrogen seal oil pump, pumped through a seal oil cooler, and returns to the generator to perform its sealing function. Fresh water from the fresh water coolers in the lower pump room also functions as the cooling fluid for this heat exchanger.

During plant shut downs and overseas passage of the barge, the turning gear is operated to revolve the spindle at a speed of 1½ to 3 r.p.m. in order to insure maintaining an adequate oil film, as well as to prevent deflection of the shaft, as would occur if it were to be left stationary. A turning gear oil pump provides the oil pressure during this operation. When the turbine is being started from a complete shut-down, the turning gear is shut off automatically as its clutch is disengaged when the turbine shaft speed exceeds 3 r.p.m. Lubrication continues from the turning gear oil pump until its motor is shut off by hand. Meanwhile, steam is admitted to the turbine of a steam driven auxiliary oil pump, also located in the turbine lubrication oil reservoir. This pump provides the 150 psi. of oil pressure required to open the emergency stop valve, as well as the 25 psi. oil for journal lubrication of the turbine and generator. When the speed of the main turbine reaches 1500 r.p.m., the governor on the small turbine of this auxiliary pump closes the supply of steam, as the twin worm wheel oil pumps, driven off the main shaft, take over.

The main generator, built also by the General Electric Company, is rated at 37,500 K.V.A. at 0.80 power factor; thus, at 60 cycle operation, normal full load output is 30,000 K.W. In accordance with modern American generator design, hydrogen is used in the generator casing to provide cooling for the windings and to reduce windage losses. Hydrogen cooled generators are not yet standard practice in Europe, according to the engineers at the Belgian power plant at which the RESISTANCE operated. Hydrogen is used in the generator either at a pressure of $1\frac{1}{2}$ inches of water or 16 inches of water. At the higher pressure, up to 32,000 K.W. can be generated. In sixty cycle operation, generator output to the switchboard at full load is 30,000 K.W. at 13800 volts, at a speed of 3600 r.p.m.; for fifty cycles, these figures are in the five to six ratio, resulting in 25,000 K.W., 11,500 volts, and 3,000 r.p.m. The generator is protected by General Electric I. J. D. differential relays. Should a short circuit occur between any two of the three phases, the over current relay between these two phases trips the oil circuit breaker, thus taking the generator off the line, and also activates the solenoid of the hand and solenoid trip valve on the hydraulic line to the emergency stop valve so that this valve will close. With no load on the generator, it would tend to over speed but for the fact that closing the throttle valve cuts off the supply of steam to the turbine. The diagram (Fig. 4) indicates quite clearly, the electrical connections for this protection. Six current transformers, three I. J. D. differential relays and an H. E. A. multi contact relay are actually the operating media installed. Further protection is provided for the frequency changer; for on the motor end of its shaft is mounted an overspeed tripping device set to trip its motor when the speed of the turbine exceeds 4000 r.p.m.. This device can be reset once the speed of the turbine is reduced to less than 4000 r.p.m., unless a short circuit exists in the station line when the lockout relay keeps the overspeed device on the frequency changer locked out. The main generator ground relay is also set up to trip the oil circuit breaker in the same manner as the main generator phase 1, 2, 3 over-current relays, as noted previously.

CONDENSING EQUIPMENT

Hung from the turbine exhaust on either side of the boat is a standard Foster-Wheeler condenser, containing horizontal tubes 7/8 inch in diameter. The tubes are of arsenical Admiralty containing about 0.03% of arsenic. Raw water, entering the system at the fore end of the vessel, passes through the traveling screens and thence into the 42 inch ducts on each side of the plant to the circulating water pumps; these pumps are located at the inlet to the two condensers. The ducts again take off from the discharge side of the condenser tubes, to carry the cooling water rearward to be spilled overboard at the stern of the plant. Each of these vertical motor driven circulating pumps requires filtered water for cooling its bearings. Two-speed motors are installed for economical operation. During the cold seasons, the pumps are supposed to be run at low speed, and in summer months, at higher speed to supply more water at the higher temperature of the river or ocean. Actually, however, sufficient cooling is obtained with the pumps at low speed, even in the warm seasons.

An automatic Belfield controller maintains a proper condensate level in each of the two hotwells. Two condensate pumps, taking condensate from each hotwell, are designed to produce the pressure needed to force the feedwater through the low pressure heater, the evaporator condenser and thence into the deaerator. A two stage multi-jet air ejector, with inter and after condensers, provides the vacuum for each of the two main condensers; these ejectors are of 5 cubic ft. per minute of free air capacity. The driving steam is taken off the main superheated steam line on the boiler side of the emergency stop valve and is throttled to 300 p.s.i. g. for full load operation of the jets. A vacuum of 1.5" Hg. absolute is obtainable with both ejectors in operation. The steam sides of the two main condensers are connected, so that one ejector may be taken out of service for repair or cleaning while operation of the plant continues. A salinity indicator cell is installed in the condensate discharge lines from each group of two condensate pumps; the salinity indicators are mounted on the turbine control panel. The cell measures the conductivity of the condensate, so that with more chloride ions in solution, the condensate is a better conductor of electricity. Thus, the amount of salt in the condensate is determined; when a certain amount is exceeded, an annunciator alarm sounds. This fact indicates either a condensate leakage or excessive carry over in the steam to the turbine.

BOILER

The floating power plants are all equipped with two Babcock & Wilcox marine express type boilers, designed for a high output and maximum compactness. Steam is generated at 900 psi. gage pressure and 900° F temperature at a rate of 170,000 LB./HR. at rated load for each boiler. The boilers are designed to burn either furnace oil or natural gas, in order to exploit the advantage of the area in which it may be operating (in oil producing regions, or where natural gas is inexpensive).

The radiant furnace is divided into two separate sections, the superheated and the saturated sides; reference to Fig. 5 (the drawing of the boiler) brings out pictorially, the relation between the two furnace sections. The entire rear and front walls of both sides are refractory surfaces; the outside wall and roof of the superheated side are water wall surfaces. Steam generated in these tubes returns to the steam drum of the boiler, having emanated from the water wall header. This latter drum receives its supply of water by means of down-comers from the lower portion of the steam drum; these down-comers are 4" tubes, located in the air space between the internal and exterior boiler casings. By keeping these tubes relatively cool, proper direction of steam and water flow is assured. It is the superheater that actually divides the boilers into two furnaces. As pictured in the sketch of the boiler, screen tubes on both sides of the superheater serve as a protection for it in order to lessen the possibility of burning out any of its tubes. These screen tubes are generating tubes, extending from the water wall header up into the steam drum. Down-comers located in the air space between the boiler casings supply the screen header with water from the bottom of the steam drum. The main bank of steam generating tubes is located on the saturated side of the furnace. Their source of supply is the water drum, which is much larger than the water wall header or the screen header. The particular operating advantage of a divided furnace of this type is the close control of superheat or main outlet steam temperature, obtained by varying the number of burners in operation on the superheated side.

Thus, it can be seen that the boiler, though having two separate furnaces, is of single up-take. Baffles are installed, as shown in the drawing, both to protect the superheater from direct flame and to make certain that all the burned gases in the superheated furnace do pass through the superheater, and not around it. These gases then combine with those of the saturated furnace, passing on up through the generating tubes. Just above the generating tubes is installed the economizer, consisting of horizontal U-tubes emanating from four horizontal headers. Beyond the economizer in the path of the furnace gases on their way to the stack is the air preheater; this consists of straight tubes through which flow the combustion air in a single pass. The forced draft fan discharges the air to the air preheater at the front of the boiler; emerging from the rear of the preheater, the air passes downward at the back of the boiler between the internal and external casings, thence under the furnace floor between it and the tank top of the barge, and finally up into the front boiler air space to the superheated and saturated wind boxes. With this design, the air becomes preheated, it serves as an insulation between the boiler casings, and it cools the water in the down-comers so that proper direction of water circulation is assured. The forced draft fan is directly connected to a two-speed motor; the designers of the plant felt that for the purpose for which the power plants were to be used (emergency spasmodic operation), a variable type of drive such as a slip coupling or a steam turbine drive would not justify their added expense. It was intended that the plant be operated at full load during emergencies, so a constant speed motor would suffice since rated fan capacity would ordinarily be demanded. The fan is operated at the slower speed only during the time when the boiler is being placed into operation after a shut down; the fan motor is switched on to high speed when the steam flow reaches 75,000 LB. per hour. Thus, the output of the fan is controlled by dampers, rather than a variable speed drive; there are inlet dampers on the suction side of the fan. In addition, an air admission damper is mounted in the air space underneath the furnace floor at the entrance to the superheated and to the saturated furnaces. In this manner, close control of the fuel-air ratio to the two furnaces is maintained. All these three dampers are operated by pneumatic-mechanical operators normally controlled by the Bailey Automatic Combustion Control; under manual control, they are also operated from the control board with compressed air as the impulse-transmitting medium, but the impulses are originated by hand rather than by a fuel-air ratio controller. A fourth damper, in the combustion air system, is mounted at the entrance to the air preheater; this by-pass damper is operated by a hand lever directly connected. At loads of 75,000 LB./HR. of steam flow and below, this damper should be open so that air by-passes the air preheater, flowing directly down the front of the boiler to the wind boxes. Above this rate of steam flow, the by-pass damper should be closed, so that the air preheater is utilized. The temperature of the flue gases is relatively low when the boiler is being put into service; thus the cold air rushing through the air preheater tubes would result in some condensation of moisture on the outside of the tubes; most furnace oils have a sulfur content, so that sulfur would be deposited on the air preheater tubes. Thus, on the external tube surfaces sulfurous acid would be formed, which would eventually destroy these tubes. There is one further type of damper in the combustion air system; at each individual burner is fitted an air register, which is hand operated to adjust for the air requirements of its own burner. The wind box pressure varies with the main damper changes, so that but for these air registers some of the burners would receive too much air and others, too little. The result would be smoky fires and inefficient combustion, with accompanying waste of fuel. The forced draft fan draws its air supply both from the boiler room and from without the ship as has previously been noted. The temperatures of these two supplies of air are greatly different in winter time; the outside air might be 15° F, while that in the boiler room is 110° F. Noting this fact firmly establishes the likelihood of moisture condensation in the air preheater if it is employed while starting up the boiler from a complete shut-down.

Feedwater proceeds from the economizer outlet through a check valve to the steam drum, which it enters at the front. In order to obtain equal distribution of the relatively cold feed water along the length of the drum, the water passes into a tube which extends nearly to the rearmost portion of the steam drum; distributed at regular intervals along the top of this feeding tube are holes ½ inch in diameter, out of which the water is allowed to pass. Cyclone steam separators are located on both sides above the drum, above the water line so as to provide completely dry steam both to the superheater and to the saturated auxiliary steam line. Chemicals in solution are admitted into the steam drum through a small line at the rear. The small positive displacement pump that pumps the chemical solutions into the drum can be also used to provide pressure in hydrostatic tests of the boiler system. Each boiler and economizer filled to normal steaming level, holds 21,300 LBS. of water; at a rate of 170,000 LBS. per hour steam flow, the water is completely changed once in every $7\frac{1}{2}$ minutes.

In each of the two boiler rooms, extending from the top deck down to the main deck in front of the boiler, is a fuel oil settling tank of 14,300 gallons capacity. Sludge in the fuel oil is drained off the bottom of this tank and piped to the bilge system. The settling tank is fitted with heating coils, utilizing the steam from the contaminated evaporator; the oil is heated in these tanks predominantly for ease of pumping, not for preheating. The latter operation is provided by means of three shell and tube oil heaters, contaminated steam being passed through the tubes; oil enters these heaters at 90°F and emerges at 180° to 200°F. Close control of the oil temperature is obtainable by means of recirculation lines; oil heated to the proper temperature facilitates combustion so that maximum utilization of the heat value of the oil is realized. Two screw type fuel oil service pumps, receiving their supply of oil from the positive head provided by the elevation of the settling tank, discharge at 300 psi.g. pressure; only one pump is required in service at one time. All the burners used for both the saturated and superheated furnaces are interchangeable; a small and a large size sprayer plate are inserted into the burner tip at low and high steaming rates respectively. The burner shaft consists of concentric tubes through the inner of which passes the heated fuel oil, while atomizing steam flows through the outer. The atomizing steam comes from the 900/450 psi.g. reducing valve station and through supplemental reducing valves to the atomizing steam header of each boiler; thus this steam emanates directly from the steam drum of the boiler, and is from an entirely separate system from the contaminated steam used in heating the oil. B. & W. recommends that atomizing steam be used for all boiler loads up to 100,000 LB./Hr. steam flow; at greater loads the higher furnace temperature eliminates the need for atomization of the fuel oil by steam. There are three burners on the saturated side and six at the superheated furnace; at normal operation of the boiler (150,000 LB./HR.) it is necessary to place only two burners and five burners into operation respectively in the two furnaces.

Starting a boiler up from a cold shut-down, the operator has no contaminated steam with which to heat the oil in the settling tank and in the fuel oil heaters; for the contaminated steam is itself generated by means of either steam off the saturated auxiliary line from the steam drum or off the 9th stage turbine extraction line. Hence, the boiler must be lighted off with the lighter diesel oil; this higher grade fuel has a lower flash point than Bunker C (or other low grade furnace oil ordinarily burned in the boilers). One burner is fired on the saturated side with diesel oil until sufficient steam is generated to place the contaminated evaporator into service. At this point, the boiler is secured and lighted off once again with heated fuel oil, utilizing atomizing steam and the small sprayer plate.

The superheater, which is the convection type, such that the flame can't "see" the superheater tubes, as previously noted, divides the boiler furnace into two sections. Two 5 inch lines take off from the steam space in the top of the steam drum with saturated steam that has passed through the cyclone steam separators and scrubbers. The three vertical superheater headers are located in the aft end of the boiler; both 5 inch saturated steam lines enter the top half of the same header. The U-tubes that comprise the superheater proper extend horizontally to the boiler front, returning again to the vertical headers. The outlet header is merely the bottom half of the inlet header, which is divided by a diaphragm with a small hole in it for draining purposes. The other two superheater headers, not being divided, have a continuous steam space. The hand hole plates in these headers are not screwed on as are the hand hole plates of the other boiler headers, but they are welded securely. When the boiler is being brought up to pressure, the superheated furnace is not lighted off until a sufficient flow through the superheater is established to assure transferring the heat lest the tubes burn out. With the turbine emergency stop valve closed, the flow is provided by a 3/4 inch circulating line exhausting to atmosphere. The minimum flow through the superheater tubes before the first burner of the superheater furnace should be lighted is 19.000 LH/HR.; likewise, the temperature of this vented steam after the superheater fires are burning should not be allowed to exceed 910°F.

Each boiler is provided with nine low pressure Diamond soot blowers and two high pressure I.H. blowers. The chain, ratchet operated type, low pressure blowers, are supplied steam from the 900/450 psi.g. pressure reducing station of the auxiliary saturated steam line. These blowers serve to clean the tubes of the superheater, generating tubes on the saturated side, economizer and air preheater. The two high pressure blowers, valve operated, receive saturated steam at 900 psi.g. from the auxiliary steam line; these soot blowers are mounted on the roof of the superheated furnace, their function being to clean the steam generating tubes which comprise the water wall.

PUMP ROOM EQUIPMENT

The largest item of equipment in the pump room is the deaerator; this is an open type feedwater heater, the main task of which is to assure oxygen free feedwater for the boiler system - the upper limit for oxygen in the feedwater is 0.003 ml. per liter. Horizontal trays are the only items inside; water enters at the top and cascades over the trays, as it is permeated by the steam. At full load on the turbine, the normal deaerator pressure is 40 psi.g.; at lower loads, the pressure is correspondingly less. Heating steam can be supplied from the 9th or the 13th stage of the turbine, though 13th stage extraction steam is normally utilized. All drip and trapped condensate eventually find their way back to the deaerator, after having been collected in the drip tank. The deaerator is mounted high in the pump room to provide a high positive static head to the inlets of the boiler feed pumps. Three main six-stage feed pumps are provided, located in a pit at the level of the bottom of barge; two pumps are required in operation when both boilers are steaming at or near full load generation. Two of the pumps are electric motor driven, and the third (reserved as a standby) is driven by a 361 HP turbine. To drive this latter pump, steam is obtained either from the 6th stage extraction of the main turbine, or from the 450/275 psi.g. pressure reducing station in the auxiliary steam line from the boiler. Recirculation controllers are provided on each of these three pumps for the purpose of maintaining a constant flow of water through the pumps. In any situation in which the boiler feed regulators would close completely, there would be no water flow through the pumps. If this condition were permitted to exist for even a short duration of time, serious damage would be incurred by the impeller wearing rings and interstage bushings within the pumps. For the protection, then, of the pumps, the recirculation controllers are designed to open automatically with the ascension of the boiler feed pressure and the reduction of flow from normal, as would result if the feedwater regulators on the boilers closed. When this condition is corrected, the recirculation controllers close automatically. In addition, venting lines are provided on the pumps, for the release of all non-condensible gases and air which might not have been detrained in the deaerator; these vents lead back to the steam space in the deaerator. One other boiler feed pump is provided - a starting boiler feed pump. When the boiler is being put into operation, the pressure in the steam drum is low, and the water demand by the boiler is limited to the small amount of steam generated and passing out to atmosphere through the superheater circulating line; it would be uneconomical to run one of the main boiler feed pumps; in addition, excess power would be demanded of the diesel engines, used in starting. The starting boiler feed pump, then, is employed until the boiler steam drum pressure reaches 350-400 psi.g., for its pressure rating is 450 psi.g.

On either side of the deaerator in the pump room, but at the main deck level are the two evaporators to provide for make-up to the boiler feed system; the losses for which make-up is needed are blowdowns from the boiler, soot blowing steam, atomizing steam, losses from drains not piped to the drip tank, and losses from the saturated auxiliary steam system, that cannot be recovered. Piping arrangements provide for steam supply either from the 9th or 13th stage of the turbine, or from the 275/150 psi.g. reducing station of the auxiliary steam line; normally, however, 9th stage extraction steam is used. Operation of the evaporator is automatically controlled by the water level in the deaerator. When the water level in the deaerator drops below normal (indicating that make-up is required in the feedwater system), the valve on the steam supply line to the evaporator is caused to open by Fisher pneumatic controls; the evaporator will continue to operate until the proper water level is reestablished in the deaerator. The vapor generated passes through an 8" vapor line to the shell of the evaporator condenser, where it gives up its latent heat to the boiler feedwater upon condensing. This condensed make-up is then piped either to the shell of the low pressure heater or to the hot well. The condensed 9th stage steam emanating from the evaporator coils is piped directly into the deaerator. For each evaporator, there is installed a feed heater whereby the continuous surface blowdown from the evaporator is employed to heat the raw water entering the evaporator shell.

The evaporator condenser is also located in the pump room; it, like the low and high pressure heaters, is a vertically mounted shell and tube heat exchanger, in which the heating medium is on the shell side. Except for being in different places in the feedwater cycle, all these heaters function similarly, serving to elevate the temperature of the boiler feedwater as it passes through the tubes of the heaters. The low pressure heater shell is supplied by 16th stage extraction steam and condensate from the evaporator condenser; this drain from the shell of the low pressure heater is pumped right into the boiler feedwater line just as it emerges from the tubes of the heater. Operation of the evaporator condenser,wherein, it is supplied by the 8 inch vapor line from the evaporator,has been mentioned. The high pressure heater, located in the turbine room as is the low pressure heater, is supplied with 9th stage steam; this steam when condensed passes right back to the deaerator - no pump being necessary because of the high differential of pressure between the high pressure heater and the deaerator. Fig. 8, a flow diagram depicting the complete cycle, shows the piping arrangements of the various parts of the system.

The two contaminated evaporators (Reilly type), used for generating steam in a system completely isolated from the main boiler system, stand vertically in the pump room. A system separate from the main steam was deemed advisable, lest, through a leak in the heating coils in one of the oil tanks, oil enter the boiler steam system, a fact that would result in priming in the steam drum with attendant carry-over. Each of these evaporators has a production capacity of 2500 LB. per hour of vapor, generated at 60 psi.g., when supplied with steam to the coils at 170 psi.g. and feedwater at 180°F. Steam is normally supplied to the coils from the ninth stage extraction, the diaphragm on the inlet valve on this line being controlled by the shell pressure, to maintain vapor at 60 psi.g. The auxiliary saturated steam line is also piped to the contaminated evaporators, coming from the 275/150 psi. Reducing valve. But one evaporator is required in use at a given time. Condensate from the coils is piped back to the deaerator by way of steam traps. The entire schematic diagram of the contaminated evaporator system is presented in fig. 6.

In the upper level of the pump room, just fore of the deaerator, are the two 300 K.W. diesel driven generators, manufactured by the General Electric Company. These units are used for standby power and for starting up the plant. Each diesel is an Ingersoll-Rand, 6 cylinder engine, requiring 180 psi. air pressure in order to start it. The main bus and switchgear diagram (fig. 7) shows just how the generators are tied into the station bus system. There is a starboard and a port feeder, each of which extends the length of the ship, supplying the electric driven auxiliaries. Diesel generator No. 1 ties in directly (by an air circuit breaker located in the switchgear room) to the port feeder; No. 2 diesel supplies the starboard feeder. The port and starboard feeders are connected in the switch gear room by a bus tie (an air circuit breaker) so that when only small house loads are necessary (such as during overseas passage of the plant) one diesel can be used to supply power for both feeders. The port feeder supplies the No. 1 boiler feed pump and the forced draft fan in No. 1 boiler room; the starboard feeder supplies No. 2 pump and fan. Though both boilers may be started simultaneously, ordinarily one will be started at a time. In either instance, both diesels are run, and with the bus tie closed. Once the turbine is up to full speed, driven by saturated steam, one of the transformers can be synchronized with the two diesels, running in parallel. If No. 1 boiler was the only boiler in service, the No. 1 transformer would be the one to be paralleled with the house load. At this point, the bus tie is opened so that No. 1 transformer supplies the port feeder, and No. 2 diesel supplies the starboard feeder. The bus tie and the two auxiliary transformers A.C.B.'s have an interlock system, wherein, there are two keys for three air circuit breakers. Thus, transformer No. 2 cannot be paralleled with No. 1 transformer (for the bus tie is kept open), but must necessarily be paralleled with No. 2 diesel generator only. During normal plant operation, then, each transformer supplies its feeder, with the bus tie open. These auxiliary transformers step the generated voltage down to 440 volts, which is that employed in the auxiliaries. Lighting transformers are located throughout the plant for 110 volts, used in the lights and small motors.

The main bus and switch-gear diagram (Fig. 7) illustrates by means of a one line diagram the main electrical connections of the main bus as well as of the station bus. As noted previously, the oil circuit breaker is set to open upon impulse of the over-current relays. Generator surge protective arrestors are connected on the generator side of the main transformer, and lightning arrestors, on the shore side. The main ΔY. wound Westinghouse 37,500 K.V.A. transformer has several steps that can be utilized; maximum stepping up of the voltage is 10 to 1 so that 138,000 volts is obtainable. This transformer is cooled by oil, which, in turn, is cooled by means of the fresh water system.

As a summary of the plant description, an over-all flow diagram (Fig. 8) is included, inter-relating the main items of equipment in the steam cycle. The following is the main feedwater cycle, that can be traced on Fig. 8. Saturated steam from the cyclone separators in the steam drum passes through the superheaters, to the stop valve, to the turbine steam chest, does work in the turbine, and is exhausted to the condensers. As feedwater, it is pumped by means of the condensate pumps through the low pressure heater, then through the evaporator condenser, and into the deaerator. The main boiler feed pumps draw their suction from the deaerator, and pump the feedwater through the high pressure heater, the economizer, and back into the steam drum.

OPERATION PROCEDURE

All the main items of equipment aboard a floating power plant have now been described in relatively brief fashion. An equally brief description of the main points to be considered will now be presented concerning the starting up of the plant from complete idleness. In this condition, with no power whatsoever aboard (except in the 60 cell battery, which serve to supply a few emergency lights), the starting point is the gasoline engine driven air compressor. This two cylinder engine must be started to obtain a supply of 180 psi. compressed air, since the diesel engines start as air motors. One of the two diesels can then be started, and cut in to supply the house load. Both of the electric driven air compressors are then run; the high pressure compressor will supply the air for starting the other diesel, and the low pressure compressor will supply that needed in the various pneumatic controls, upon which the plant is so very greatly dependent.

At this point, the boiler (or boilers) can be lighted off, for the forced draft fan may be run at low speed and the starting boiler feed pump put into operation. Diesel oil will be burned in the boiler, all the while operating the equipment on manual control (though low pressure air is necessary for remote control).

As saturated steam becomes available, it is admitted to one contaminated evaporator and to one main evaporator. In the turbine, steam can be admitted to the high pressure packing, and cooling water both to the high and low pressure packings. Both condensers are at this time placed into service, while bringing the vacuum up to 10 to 15 inches Hg. The turbine can be started rolling, utilizing the saturated steam in the main line, once the pressure reaches 250 psi. When full speed of 3000 r.p.m. is attained, the switchboard operator puts the turbine on house load, shutting down the diesels. The boiler is now carrying the station load on saturated steam.

Meanwhile the boiler operator has transferred to burning heavy fuel oil, heated by the steam generated in the contaminated evaporator, and inserted a large size sprayer plate in the one burner he is using on the saturated side. A main (electric driven) boiler feed pump is cut in from the boiler control panel and the starting boiler feed pump shut down when the pressure in the steam drum has reached 350 psi.g. Once a steam flow of 20,000 lb. per hour has been attained, one burner on the superheated furnace may be lighted off. The temperature and pressure may then be brought up to rated conditions of 900° Fand 900 psi.g. by regulating the rate of firing at each furnace, by means of varying the oil pressure and the number of burners. An alternate method, of equally good practice, is to bring the boiler pressure up to line condition of 900 psi.g. before lighting off the superheated side--then increasing the temperature to 900° F.

As soon as extraction steam is available, the pump room operator utilizes it in the evaporator, deaerator, and contaminated evaporator in place of saturated steam from the auxiliary line. The turbine operator admits the extraction steam to the high and

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low pressure heaters. Closing the field switch on the main generator automatically starts the motor of the frequency changer; this procedure is accomplished by the switchboard operator at the point when the turbine is ready to take on house load. With the boiler at rated conditions, the phasing out operation is all that is necessary before tying the main generator on to the line at shore. This short operational account has attempted to correlate the functional interrelationships of the machinery aboard the floating power plant.

OPERATION DIFFICULTIES

During normal operation of any steam power plant, difficulties are bound to occur periodically, such as leaking valves, steam lines, burned out pot-heads, burned out electric coils, jammed soot blowers, tubes to be rolled, grounds in the D. C. station system, in addition to normal wearing out of various items of equipment. The operation aboard the RESISTANCE included these minor shortcomings, but they are worth no more importance than mentioning. A few of the more interesting and more serious troubles encountered, however, will be described.

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1. FISH IN THE CONDENSERS

The first problem to be touched upon is that wherein we had fish in the condensers. During the spring of 1945, it was found that the pressure of the circulating water entering both condensers was building up to an abnormally high value (up to 11 or 12 psi.g.); normal discharge pressure from the circulating pumps (which are always run at low speed, even at full load on the turbine) is 3 to 4 psi.g., for these are centrifugal volute pumps of large capacity and low head. Consequently, when this condition was first noticed, one condenser was taken out of service and its water box was opened for investigation; each of the 7/8" diameter tubes was found to be clogged with three or four small fish. There was no recourse at that time but to remove the fish, close the water box, and place that condenser back into service--then to clean the other. A barrel and a half of fish was taken from each condenser and its water box. It was evident that this was the season for schools of fish to thrive in the Escaut River; the engineers in the Interescaut plant stated that the fish would run for about two and a half weeks.

The traveling screens in the screen well, obviously, were not of sufficiently fine mesh to keep these fish out of the 42" ducts. The maintenance crew was therefore assigned the task of replacing the screens in the three traveling screens with as fine mesh replacements as were obtainable. The welder fastened thin steel plates to cover any areas where the water might find its way past the screens without going through. The time and energy

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(expense is not of primary concern in the army) expended in these alterations were, nevertheless, entirely futile. The fish continued to find their way into the tubes of the condensers; in addition, they plugged the tubes of the two fresh water coolers (which are constructed such that the raw water passes through 7/8" tubes, also, with the fresh water in the shell). For the next two weeks, therefore, the turbine operator had to keep his eye on the inlet circulating water pressure at the condensers; when this pressure reached 10 psi.g., cleaning operations commenced. The plant was able to operate with but one fish cleaning job per day in each condenser, and one cleaning in one fresh water cooler (for normal operation requires but one cooler). The usual three barrels of fish from the condensers were dumped overboard along with one half barrel from the fresh water cooler. De-fishing the condensers, it might be added, was one of the tasks the deck hands were called upon to perform; the ship's medic also found himself assisting in this foul smelling chore. The situation, as noted above, was temporary, and ceased to plague the plant's operation when the fish had had their run.

2. CAVITATION OF BOILER FEED PUMPS

Another item of concern in the operation of the plant was the preventing of cavitation in the boiler feed pumps. If allowed to continue for any length of time, the erosion effect of cavitation will cause rapid destruction of the impeller, with attendent drop in efficiency, and increase of vibration and noise. The conditions under which the RESISTANCE operated were rather conducive to possible cavitation in the pumps. The German V-1 and V-2 bombs were falling frequently in the Antwerp area during the early months of 1945. A hit or near miss to a transmission line anywhere in the grid system was enough to cause a loss of balance in the phase currents in our system, so that the overcurrent relays would open the O.C.B. and close the emergency stop valve. This condition, or even a sudden drop in part of the load, resulted in a drop in pressure of the 13th stage extraction steam supplying the deaerator. There is a pressure controlled valve on the 9th stage emergency steam line to the deaerator that is adjusted to open when the pressure in the deaerator drops below a certain value. But for a complete loss of load the pressure of the 9th stage steam would be too low. The result is that the water at the high deaerator temperature would then flash to steam by reason of the pressure drop and the fact that it is close to the boiling point corresponding to the original pressure. The boiler feed pumps then become vapor bound and the noise of cavitation is evident. The pump operator has to be ever watchful of the deaerator pressure, for he does have a

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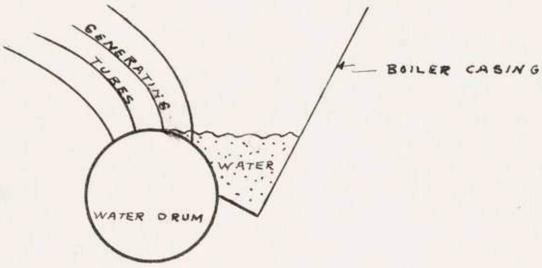
manual means of keeping the pressure up when such an emergency occurs. In the aft end of the deaerator a steam line from the 270/150 psi. pressure reducing valve enters. The operator can run over and open the hand operated valve to let the auxiliary steam enter the deaerator, thereby keeping the pressure up. This steam is certain to be up to pressure, for it comes from the saturated steam line right off the top of the steam drum.

There was another situation, which is less obvious, that resulted in potential cavitation in the feed pumps. When the main evaporator had to work hard, much more steam was sent through the 8" vapor line to be condensed in the evaporator condenser in order to provide make-up for the boiler. The boiler condensate, passing through the evaporator condenser, thus picked up more heat and thereby resulted in an increase in the temperature of the water in the deaerator. Normally, the water in the deaerator is just about at the boiling point for the pressure inside, for the principle of the deaerator is based on the fact that oxygen is least soluble in water at its boiling point (for every pressure). Therefore a slight increase in the water temperature resulted in its flashing into steam, with the accompanying cavitation. The pump room operator was obliged to pay close attention to the temperature of the feedwater leaving the evaporator condenser for this reason. If this temperature became too high, his recourse was to by pass some of the feedwater around the evaporator condenser by cracking the by-pass valves. These specific points were not obvious at first; the fact of cavitation had to be traced back to possible causes, the most likely of which were those mentioned. The deductions were verified when the preventive measures were taken.

3. TUBES EATEN AWAY BY SULFUROUS ACID

Trouble was encountered in the economizer tubes of number 1 boiler, which proved to be of very great inconvenience. The first indication of any disturbance was the appearance of water leaking out of the boiler casing at the water drum; the boiler was secured immediately in order to investigate. Upon the opening of the boiler casing at this point, a flow of water rushed out and onto the deck.



The sketch above shows where the accumulation of water was stored; a high water mark on the steam generating tubes verified the fact. Examination of the surfaces of the one inch steam generating tubes showed that some of the tubes were pitted with small holes, or partially disintegrated, at the portions below the water line. There was no indication at that point just how the water did happen to be there; the high water mark showed it to be 1½ ft. above the trough of the casing.

Those tubes with holes in them and also those that were so eaten away that failure seemed imminent were cut out by means of an oxy-acetyline torch. A stub about 3" long was left of each tube where it entered the water drum and the steam drum, lest damage occur to these drums by getting intense heat too close to them. In all, fourteen steam generating tubes were cut out; this is but a negligible fraction of the two or three thousand one inch steam generating tubes. Steel tapered plugs were hammered into the tubes that were cut out; this task necessitated removing the cyclone steam separators on one side of the steam drum to get at the steam generating tubes where they enter the drum.

After the generating tubes were plugged, a hydrostatic test showed leakage from the economizer. It was very difficult to tell just which tubes were leaking, even after the side panel at the economizer was removed, for the leak appeared to be behind several tubes toward the interior. It was finally decided that a certain few tubes were ruptured; water pressure was applied to one of these tubes where it entered one economizer header and its entrance to the other economizer header (at the other end of the U) was plugged. In this manner dripping of water was detected in three tubes. Each of these tubes was then plugged at its entrance to each of two economizer headers, so that each U-tube was plugged off.

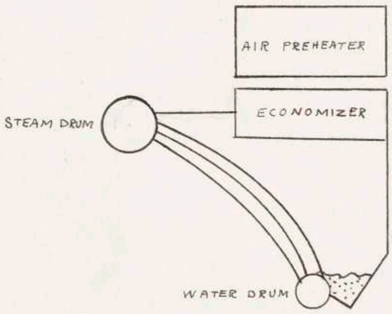
Further hydrostatic pressure test on the boiler resulted in continued dripping. Two more economizer tubes were found to be ruptured and were plugged as in the other instances. Another hydrostatic test on the boiler brought continued drippings, but a water pressure test, tube by tube with one end plugged, indicated that no more tubes were ruptured. It seemed that the headers must be leaking through the plugs and on out through the holes in the bad tubes. It was very difficult to get the plugs into the economizer tubes, working through the handholes in the small headers; plugging tubes in the steam and water drums had been a much easier task, for one is able to get right inside these drums.

In order to stop the leakage through the plugs, each was welded electrically so that beads of weld metal covered the plug and the adjacent area of the interior of the economizer headers. Continued hydrostatic tests and repeated layers of welding eventually resulted in making the boiler tight for 1100 psi.

With number 1 boiler still down, the air preheater tubes were examined to find how they had fared in the ordeal. It is possible to see only the top layer of tubes, because of the compact arrangement of the marine boiler. Several of the air tubes in the top row were found with rather large holes in them along their lengths; there is no telling how many tubes are eaten away in the many layers below the top. Nevertheless, strips of tin were used to patch the holes in the top tubes, as a rather feeble gesture to remedy the situation.

The specific troubles and how they were handled have now been mentioned; the following matter seeks to give an explanation for the failures. It is presupposed that the first rupture occurred in the economizer. It could be that sludge ($Ca_3(PO_4)_2$) deposited in the economizer tubes, as the slight amount of Na_2HPO_4 acted with the impurities of the water. This soft sludge could result in preventing heat transfer through the tubes from the hot gas to the water, so that the tube would be burned out. This explanation is unlikely, however, since examination of the economizer tubes indicated there was no sludge.

A more plausible explanation is that a boiler operator, becoming impatient while bringing a boiler up to pressure from a cold condition, perhaps admitted hot feedwater to the relatively cold economizer at too rapid a rate. The operators had been repeatedly warned against this practice with the hope that admonition would be of value. Such practice by an operator would cause strains in the tubes so that they would fail at their weakest points. Assuming this theory to be true, one can easily visualize the leakage of water building up a pool between the water drum and the boiler casing (just below the economizer).



Reference to the above sketch indicates the physical arrangement. No doubt some of the pool evaporated, but the pool was maintained liquid, as it was somewhat cooled by the outside panel of the boiler. The fuel oil that was burned in the boiler was relatively high in sulfur content. Without doubt, sulfur particles were dissolved in the pool of water at the water drum so that it was in effect a solution of sulfurous acid. Continuous contact with the thin generating tubes could only mean that they would eventually be eaten away, such as examination proved. This theory, then, very easily explains the failure of the generating tubes.

Some of the sulfur particles would, of course, pass up with the furnace gases and the vapor from the pool of water. This vapor would tend to condense as it came into contact with the relatively cold air heater tubes. This is the same situation outlined previously in describing the by-pass damper of the air preheater, except that with a pool of water available to supply a much greater quantity of water vapor to the furnace gases (than the moisture in the fuel and air), the condition for condensation on the outside of the air heater tubes is more favorable. Again, sulfur particles dissolving in this condensed vapor produce sulfurous acid. Doubtlessly, it was this acid attack that produced the holes in the air preheater tubes.

With all the repairs accomplished (14 steam generating tubes and 5 economizer tubes plugged) and with the innumerable holes in the air preheater tubes, no perceptible drop in boiler efficiency occurred after the boiler was placed into operation again. In fact, the leaking air preheater tubes did not cause a decrease in air flow that would cause the boiler to be required to take a lower load. Throughout our operation of the plant, number 1 boiler was always capable of carrying a greater load than number 2 boiler (even after this trouble). It seemed that number 2 boiler could not get enough air, for it would smoke with a load of over 150,000 lb. per hour steam flow.

4. CARBON PILES

Every time each of the boilers was opened for its periodic cleaning and inspection, there would be found on the furnace floor of both furnaces (superheated and saturated) a pile of carbon about two feet before the burners. Piles up to 8" high and 15" long were not uncommon. In addition, carbon deposits were found on the screen tubes in both the saturated and superheated furnaces; and in the superheated furnace there was always an accumulation of carbon hanging from the studded water tube ceiling. Although the Babcock & Wilcox Co. recommends that atomizing steam is unnecessary with loads above 100,000 lbs. per hour steam flow, experiments were tried using atomizing steam at the normal operation loads of the boilers; it was anticipated that more complete combustion might be obtainable with steam to assist atomization. Nevertheless, the accumulations of carbon persisted regardless of the atomizing steam; the boiler merely became more expensive to operate, as the atomizing steam was wasted. The boilers were watched carefully to see that they got sufficient air and did not smoke at their stacks. This problem was not solved in our operation of the plant; it did not prove troublesome, however, since the expense of a little extra fuel did not bother the Army in its Lend-Lease program--for the fuel oil was obtained from the British Army.

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5. CARRY OVER INTO THE SUPERHEATER

The main difficulty encountered, the one that terminated our operation of the plant, was the result of feedwater treatment; therefore, this phase of plant operation will be discussed before the failure is considered. The services of The Hall Laboratories, Inc., of Pittsburgh, Pa. were secured and retained under contract by the government to be responsible for establishing the procedure for chemical treatment and control of the boiler water of all the four floating power plants. This concern specified the water analyses to be made, the concentrations of various substances to be maintained or limited in the boiler, and the method of treatment.

Water samples were to be drawn periodically from each of the water drums, from the condensate to the low pressure heater and from the deaerator, and a sample from the shell of the evaporator in service. Limits were placed on the concentrations to be maintained in the water at these various stations. The boiler water was analyzed for phosphate concentration, alkalinity, chloride, and sulfide. The condensate obtained at the low pressure heater was tested for chloride and hardness. The feedwater at the deaerator was checked for alkalinity, phosphate, and oxygen content.

The main treatment of the boiler water specified by the Hall Laboratories was the phosphate treatment, wherein di-sodium phosphate is added to the water to precipitate the calcium and magnesium carbonates and sulfates in the form of a sludge that

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can be blown off. Di-sodium phosphate was recommended in preference to tri-sodium phosphate, for the latter causes excess alkalinity in the boiler. The di-sodium phosphate is injected directly into the steam drums as a solution by means of two Hills McCanna chemical pumps of the positive displacement type. The limits on the phosphate concentration to be maintained were placed at 50 and 80 ppm.; phosphate was to be added when the concentration dropped below 50 ppm. The upper limit on chloride concentration was placed at 100 ppm.; it was recommended that some chloride be allowed to remain in the boiler as a sort of hindrance to the phenomenon of caustic embrittlement that conceivably could occur at crevices where the alkalinity concentration might build up. Excess chloride ion was handled by blowing down the boiler. In the event of low alkalinity, sodium hydroxide was available to increase the ppm. of alkalinity. In case the deaerator might be unable to remove all the oxygen from the feedwater, sodium sulfide was to be added to the boiler water to handle the oxygen.

The condensate from the condensers was checked for chlorides and hardness to ascertain that there was no leakage in the condensers. A rise in the concentrations of these items would indicate contamination of the condensate, with a leaky condenser being the most likely source of the trouble. The Babcock & Wilcox boiler book recommends limiting the total solids in the boiler to a maximum of 1700 ppm. (this includes a chloride ion concentration of 500 ppm.). The usual practice aboard the plant was to run with total solids between 400 and 600 ppm., which is obtainable by adhering to the Hall specifications.

The water in the shell of the evaporator was tested to determine the number of concentrations of chloride in order that the proper amount of evaporator blow down could be effected to prevent carry over in the event the chloride concentration became too high.

Hall Laboratories recommended testing the feedwater at the deaerator for phosphate in order that a slight phosphate concentration might be maintained. From each water drum of the boilers there is a recirculating line back to the deaerator; these lines are installed for the purpose of getting phosphate into the water in the deaerator. By adjusting the valves, the proper amount of phosphate can be maintained in the deaerator; likewise, the alkalinity in the feedwater is controlled by the same method. In addition, the concentrations of all substances in the two boilers can be equalized by regulating the flow through these two recirculating lines. If boiler number 1 is lower in alkalinity and phosphate than number 2, the flow through the recirculation line of the latter can be increased and through the former, decreased to effect equality of concentrations. The oxygen content in the feedwater in the deaerator was periodically checked by means of the Winkler test. It was advised to keep the oxygen content of the feedwater less than 0.003 c.c. per liter; increasing the venting of the deaerator by opening the valve in the venting line is the procedure for maintaining the limit on oxygen. At no time during the operation of the plant was there ever any indication of oxygen in the feedwater. The chemist of

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the Interescaut Plant made tests by methods other than the Winkler test, and he likewise obtained a value of zero as the oxygen content. In addition, this chemist was engaged to make independent analyses of the other chemical concentrations, as a check to those made aboard the ship; very good comparisons were obtained.

The above procedure, then, was the feedwater treatment adhered to aboard the Resistance; the plant was operated from January 1945 to July 1945 without mishap due to feedwater troubles. Then, with a plant load of 30,000 K.W., number 1 boiler ruptured some tubes early in the morning of 29th July; within one half hour the other boiler also blew so that steam was issuing profusely from both stacks. At the present writing, the plant has not been in operation since; it is undergoing repairs at Portsmouth, New Hampshire.

When the boilers had cooled enough to permit entrance, it was found that each had a few ruptured superheater tubes, the holes having occurred in the tubes about a foot in front of the header closest to the superheated furnace. These tubes could not be reached to be cut out, nor could they be plugged, since the hand-hole plates of the header are welded in. These hand-hole plates, near the ruptured tubes, were cut out in order to obtain a sample of any solids that might be lining the inner surface of the tubes. Such carry over was found, indicating without any doubt that heat transfer was prevented from the hot gases through the tube to the steam so that the tube burned out.

A sample of this solid material was given to the Interescaut chemist to analyze. It was composed of practically the same constituents as were found on the turbine blades in a Belgian plant that had experienced similar trouble in 1943. The top of the emergency stop value was removed, exposing its steam strainer encrusted with the same pinkish solid material.

Carry over, therefore, resulted in complete shut down of the boilers and the termination of the European operation of the RESISTANCE. The feedwater control situation during the time leading up to the ruptures must be examined in order to obtain the complete answer. The waters of the Scheldt River vary considerably in brine content with the seasons. During the winter months, a chloride analyses indicated a concentration of about 50 ppm. of chloride ion in the river water; at the time the tubes in the boilers blew it was found that the concentration of chloride was about 2000 ppm. (practically salt water).

About a week and a half before the ruptures occurred, the chloride concentrations in the boilers began to get out of hand. In order to keep the Chloride ion less than 100 ppm. it was necessary to blow downthe boilers more and more; this operation blew out not only the chloride, but also the alkalinity and phosphate so that increasing amounts of $Na OH$ and $Na_2 HPO_4$ were required to be added. The high salinity content of the raw water made it imperative that the evaporator be blown down more frequently. Since more water was being blown overboard from the boilers a greater demand for make up was required of the evaporator so that it was necessary to place both of them in use. Chloride was carried over in the vapor lines from the evaporators, as they were working hard to meet the supply of make-up needed. Analysis of the condensate as it entered the low pressure heater showed an abnormally high chloride content (which conceivably could have been a result of a leaking condenser but for the fact the condenser was later checked to be sound).

Thus, the high chloride content of the river water was continuously making the feedwater situation more serious. It was decided to shut down the plant and either wait until the river water became less salty or to move to a location where a supply of fresh water could be obtained for the source feeding the evaporator. But there was a dire coal shortage in Belgium; all the power obtainable was necessary, so at the risk of the plant it was ordered by the Army to continue operation. It was attempted to run at reduced boiler loads and at lower water level to forestall the carry over that was known to be taking place. The plant operators were plagued with this situation until finally the boilers blew; the Army could no longer coerce the plant into continuing operation.

U. S. Civilian engineer experts were soon after sent to the plant to estimate the damage and attempt to ascertain the direct cause. When told the facts, they had to agree with the point of view held by the ship's crew. Examination of the literature pertaining to the evaporators, made by one of the civilians, brought to light the fact that the evaporators were intended to evaporate fresh water (not salt) in their operation in order for the guarantee against a certain amount of carry over to be valid. Evidently, this fact was not realized by the engineers who redesigned the plant for overseas operation back in 1944; for, to meet the situation wherein salt water would have to be the source of water supply for the evaporators, the designing engineers merely added an extra evaporator of the same type to handle the extra amount of feed water that would be necessary as a result of increased blow down.

It is a relevant fact that the SEAPOWER, operating in Ghent, Belgium, had no such trouble; for it operated in a canal, so that its source of supply for the evaporators was fresh water the year round. It was attempted to obtain a fresh water supply to the evaporators when the RESISTANCE first tied up to the power plant at Schelle, but the Interescaut engineers maintained they had barely enough fresh water for their own evaporators; in fact, it was continuously a source of friction to obtain from them five tons of water per day needed for the fresh water cooling systems and drinking and lavatory purposes aboard. The INDUCTANCE at Pensacola, Florida and the RESISTANCE in its test runs in the U. S. had always used a fresh water supply to the evaporators.

An error in the selection of a piece of equipment, therefore, resulted in serious damage to the boiler; for it will be a major repair to put new tubes into the superheaters of both boilers. Entrance into the condenser permits examination of only the blades of the 19th stage of the turbine; these blades were as clean as if they had been polished, but the condition of the blades of the other stages could not be ascertained without removing the turbine casing.

6. CLEANING PROBLEMS

Maintaining clean exterior boiler tube surfaces proved also to be a troublesome problem. The compact size of the boilers, though necessary on a ship in order to provide high capacity output per unit volume, was in part responsible. The type of oil burned (English furnace oil) was, as previously noted, high in sulfur content, so that hard scale was prone to form on the external surfaces of the boiler tubes. It was in the cleaning of these tubes that the compactness of the installation proved troublesome.

Experience showed that the boilers could not be operated at full load for more than three weeks without their having to be secured and cleaned. The screen tubes and the outer few rows of generating tubes were able to be cleaned by chipping the scale off with metal rods. Where it is most necessary to have clean tubes, however, is in the superheater; and the compact design has the superheater tubes squeezed closely between the screen tubes. It is possible for a man to enter the space between the superheater and the screen tubes of the saturated side of the boiler; yet his quarters are extremely cramped and he can scrape the scale off only the two outside rows of superheater tubes. Furthermore, it is impossible to enter the samll clearance space between the superheater and the screen tubes of the saturated side, so that only two rows of the superheater can be scraped, these facing the saturated side. The obvious result, was that more oil had to be burned in the superheated furnace to maintain the 900° F. outlet temperature, since heat had difficulty in

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being transferred through the scale on the external tube surfaces.

Therefore, barring of the tube surfaces, though better than no effort whatsoever, was far from satisfactory. At a time when one of the boilers required new brick for the furnace floors, it was attempted to wash the hard scale off--there was no worry about the effect of water upon the brickwork since it was to be removed anyway. A hose was rigged whereby anything from cold water to wet steam could be played upon the tube surfaces by adjusting the relative amounts of water and steam in the mixing chamber. This operation was attempted with the boiler shut down, so that a man could enter the furnace and play the jet upon the tubes a few rows behind those outside. In this manner the warm water or steam could be turned upon the inner rows of the superheater. It was found, however, that regardless of the water-steam mixture the scale would not come off from washing alone. The water did soften the scale considerably so that it was much more easily removed by means of rods; yet the fact remains that though it became soft, the slag could still not be reached to be knocked off in the inaccessible area such as the superheater.

With superheater tubes partially clogged with scale, the furnace gases from the superheater side encountered increased resistance to their flow between the tubes of the superheater. It was not long before the baffle between the bottom of the steam drum and the middle of the superheater in both boilers became burned out. (This baffle is shown on the boiler sketch in Fig. 5). The superheater gases then found a passageway of least resistance, so that they tended to by-pass the superheater, a condition adding to the amount of oil required in the superheater burners to maintain the desired outlet temperature. The ship's maintenance crew did not have the facilities with which to replace these baffles, so that the condition existed continuously.

Operation of the INDUCTANCE, while the crew was in its training stage in Pensacola, Florida, revealed no such scaling of tubes. Burning natural gas, the INDUCTANCE was free from the difficulties encountered in the slag producing furnace oils. With natural gas as a fuel, then, the compactness of the floating power plants offers no drawback in normal operation. The crew aboard the RESISTANCE never did solve the problem of effecting clean boiler tubes, nor did the other crews operating with oil.

PLANT PERFORMANCE

The results of the plant performance of the RESISTANCE, as calculated in this paper, were obtained from data recorded on 30th March, 1945. This day was selected since the plant was operating at its maximum possible output. Rated load for the generator at 60 cycles is 30,000 K.W.; while at 50 cycles, it might be expected to be 25,000 K.W. On 30th March, 1945 the plant averaged 31,050 K.W. at a frequency of 50 cycles over the twenty-four hour period. The values of various flows thus obtained may be expected to be at their highest. Since the plant was operating over its rated capacity, the efficiencies may be expected to be somewhat lower on this day than during a period of normal load operation. Actually, the deviations of the efficiencies from those at rated load were relatively small.

All calculated data is tabulated near the end of this paper as a result sheet. The 745,000 K.W.-HR. gross generator output and the 715,000 K.W.-HRS. net generator output indicate that the station or house load was 30,000 K.W.-HRS. during the twenty-four hours of continuous plant operation. This is 4% of the gross output, but it should be noted that this value is somewhat higher than that which is actually necessary to operate the plant. Included in the house load are the power for running the ship's galley, refrigeration machinery, the capstans, and a few other small items of equipment that do not pertain to the manufacturing of electricity. It is true, however, that these items even in total are negligible relative to the generator output, but it is well to recognize their existence.

The calculations prove the fact that NO. 1 boiler is capable of utilizing more air than boiler NO. 2; the former used 14% excess air, while the latter consumed 11.5%. It was always found that NO.2 boiler would commence smoking at high loads, a fact that indicated it was not receiving sufficient fresh air. This condition existed both before and after the air preheater tubes in NO. 1 boiler were damaged by reason of the economizer leak in that boiler. The trouble in the economizer occurred in May 1945, two months after this data was recorded; even then NO. 1 boiler could take higher loads without smoking. Thus, NO. 1 boiler received more air to its burners even after some of its air supply was by-passing the boiler and going on up the flue through the holes in the damaged air preheater tubes.

There was no precise method of ascertaining the exact condition curve of the turbine; the method used for these calculations was as follows. The heat balance diagram furnished by the General Electric Company gives the pressures and enthalpies of the steam at the 9th, the 13th, and the 16th stages, and in the condenser these points were plotted on a Molier Chart, along with the initial steam condition, which is established by pressure and temperature. Through these five points a curve was drawn, which was taken to be the condition curve of the turbine. On 30th March the turbine had a different load and speed from that of the G. E. test, but the pressures at the various stages were obtained from the pressure gages. The intersection of the 9th stage pressure with the condition curve established the condition of the 9th stage on the Molier Chart so that its enthalpy could be read. In like manner were the enthalpies of the other stages obtained.

In a regenerative cycle the water rate (pounds of steam per kilowatt-hour) is meaningless; although in a cycle without extraction feed water heating it is a good measure of performance. Somewhat equivalent in the regenerative cycle is the heat rate; this is the amount of heat supplied the turbine by the steam less the amount of heat in the feedwater before the economizer all divided by the output of the generator. For the run of 30th March, 1945 the heat rate was calculated to be 10,780 BTU. per K.W.-HR. The heat balance diagram supplied by G. E. gives a value of 9,770 BTU. per K.W.-HR.; but this is for the theoretical heat rate and is thus a limit to be approached, but not reached. In a modern plant operating on the regenerative cycle, a heat rate of less than 11,000 BTU. per K.W.-HR. is considered very good.

The overall plant of efficiency, as calculated from the BTU. content of the fuel through the entire plant to the switchboard, was found to be 26.6% as based on gross output and 25.5% as based on net output. This value of utilizing for power about one-fourth of the energy supplied is to be expected in a heat cycle. Over a period of many weeks of operation of the plant the overall efficiency did not vary markedly as long as the load was above 20,000 K.W. At the lower loads, the plant efficiency was somewhat less, but not very greatly so.

Based on gross output, the plant burned oil at the rate of 0.693 pounds per kilowatt-hour; this value is 0.723 when based on the net output of energy delivered to shore. Modern ocean vessels are able to obtain performances of from 0.40 to 0.50 LBS.

of fuel per horse power-hour; the 0.693 LB/K.W.-HR. of the RESISTANCE is 0.517 LBS. per horse power-hour. The Savannah (one of the first steam vessels to cross the Atlantic) burned fuel at the rate of about 14 pounds per horse-power hour. The operation of the RESISTANCE, then, compares quite favorably with modern power installations, both marine and stationary.

POSTWAR OPERATION OF FLOATING POWER PLANTS

At the present writing, the following is the disposition of the four floating power plants. The INDUCTANCE remains at Jacksonville, Florida, where it continues its electrical production for that area. The IMPEDANCE was sold by the U. S. Army to the Philippines; it is now in operation in Manila by the local civil authorities. Puerto Rico was seeking to purchase the SEA POWER, but the exact disposition of this plant is unknown to the author. Finally, the RESISTANCE was purchased by the Public Service Company of New Hampshire. This utility company is at the present time accomplishing the repairs to the superheaters and other damaged items; this work is being done at Portsmouth, New Hampshire, the city in which it is intended to operate the RESISTANCE.

In view of the Army's extreme eagerness to get rid of these plants, it does not appear that they are being considered as a major steam-electric unit of the future. There is no doubt but that the Army wants no part of them any more; and, there is no other concern wishing to build them. Therefore, it may be considered that the floating power plants were a war-time experiment, which was partially successful, but will not be further developed.

During the period of operation of the RESISTANCE in Belgium, innumerable visitors from various countries came aboard to see the plant. Shortly thereafter, England was seeking ten to fifteen such plants; in addition, Russia, Belgium, Holland, and France asked if it would be possible to obtain some. But these countries did not wish to buy them; they hoped to obtain some plants under the Lend-Lease program--with the accent most strongly on "Lend".

The United States did not meet these requests, but did come up with an alternative. Packaged boilers were developed during the war time period to meet special requirements. These boilers are compact, simple, reliable, prefabricated units of small output to be used in isolated regions; they were designed to be self starting since they were intended for areas having no other source of power. The first design was made for use in small isolated communities in Russia and Siberia; the 1000 K.W. plant was constructed so that it could burn Russian coal, lignite, peat, or wood. Three other designs were later completed--of 500 K.W., 2000 K.W., and 3000 K. W. capacity.

Thus, the development of these packaged boilers seems further to preclude the likelihood of floating power plants of the RESISTANCE type in the future. A packaged boiler is a much more economical and simple unit to employ for emergency or temporary conditions than a $5,000,000 floating powerhouse. It is rare that a land powerhouse is inundated by flood waters, and certainly no bombings are expected during peace time. Consequently, it appears that the floating power plant has seen its day, and that where emergency plants are required some such unit as the packaged boiler will be employed.

BIBLIOGRAPHY

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Fig. 260, p.556

RESULTS OF PLANT PERFORMANCE TEST

Generator Frequency	50 Cycles
24 HR. Gross Generator Output= 745,000 KW-HRS.	24 HR. Net Output= 715,000 KW.-HRS.
House Load	30,000 KW.-HRS.
Gross Rate of Output: 31,050 K.W.	Net Rate= 29,800 K.W.

	NO.1 Boiler	NO.2 Boiler	Both Boilers
Steam Flow (LB/HR.)	158,000	141,000	299,000
Feedwater Flow (LB/HR.)	163,000	146,000	309,000
Fuel Oil Flow (LB/HR.)	11,140	10,420	21,560
Air Flow (LB/HR.)	166,000	152,000	318,000
Boiler Efficiencies (%)	86.4	82.1	84.3
Excess Air (%)	14	11.5	13
Make-up			10,000 LB/HR.
Make-up			3.2%
Heat Entering Boilers			498,000,000 BTU/HR.
LB. of Air Per LB. Fuel (Actual)			14.3
LB. of Air Per LB. Fuel (Theoretical)			13.08
Heat Recirculated By Preheater			24,800,000 BTU/HR.
9th Stage Extraction			38,000 LB/HR.
13th Stage Extraction			9,500 LB/HR.
16th Stage Extraction			24,000 LB/HR.
Steam To Air Ejectors			670 LB/HR.
Condenser Flow			226,600 LB/HR.

	Both Boilers
Heat Given Up In Turbine	113,600,000 BTU/HR.
Gross Rate of Generator Output	105,800,000 BTU/HR.
Mechanical & Electrical Losses	7,800,000 BTU/HR.
Mechanical Losses	5,750,000 BTU/HR.
Electrical Losses	2,050,000 BTU/HR.
Generator Efficiency	98.2 %
Mechanical Efficiency of Turbine	95.0 %
Plant Heat Rate	10,780 BTU/KW.-HR.
Regenerative Cycle Efficiency	33.2 %
Overall Thermal Efficiency	31.7 %
Actual Thermal Efficiency	32.2 %
Overall Plant Efficiency (based on gross output)	26.6 %
Overall Plant Efficiency (based on net output)	25.5 %
LB. of Fuel Per KW.-HR. (based on gross output)	0.693
LB. of Fuel Per KW.-HR. (based on net output)	0.723

CONDITIONS & ENTHALPIES

LOCATION	CONDITION	ENTHALPY (BTU./LB.)
a	815 psi. Abs. $900^{\circ}F$	1455
b	$173 \div 0.9 = 192$ psi. Abs.	1316
c	$69 \div 0.9 = 77$ psi. Abs.	1241
d	$14.8 \div 0.9 = 16.5$ psi. Abs.	1137
e	2.6"Hg=1.28 psi. Abs.	1020
f	$108^{\circ}F$	76
g	$112^{\circ}F$	80
h	$210^{\circ}F$	178
i	$226^{\circ}F$	194
j	$265^{\circ}F$	233.5
j'	$265^{\circ}F$ 1100 psi. Gage	236.5
k	$350^{\circ}F$	321.5
E	$255^{\circ}F$ 25 psi. Abs.	1165
$g_f + 5^{\circ}F$	$117^{\circ}F$	85
$h_f + 7^{\circ}F$	$217^{\circ}F$	185
$i_f + 9.8^{\circ}F$	$236^{\circ}F$	204
$E_f + 10^{\circ}F$	$265^{\circ}F$	233.5
$k_f + 15^{\circ}F$	$365^{\circ}F$	339.5
ce	sat. at 55 psi. Abs.	1176
$180^{\circ}F$	$180^{\circ}F$	148
$ce_f + 10^{\circ}$	$297^{\circ}F$	266
q	285 psi. Abs.	1455
	X X X X X X X X X X X X X X X X	
w_1	299,000 LB/HR.	
$w_1 + W$	309,000 LB/HR.	

HEAT BALANCES AT FEEDWATER HEATERS

(1.) Low Pressure Heater

$$(w_1 - w_2 - w_3 - w_4)\; h_g + w_4 h_d + Wh_1 + 9.8^\circ F =$$

$$(w_1 - w_2 - w_3 - w_4)\; h_h + (W + w_4)\; h_h + 7^\circ$$

(2.) Evaporator Condenser

$$(w_1 - w_2 - w_3 + W)\; h_{h_o} + Wh_E =$$

$$(w_1 - w_2 - w_3 + W)\; h_i + Wh_i + 9.8^\circ$$

(3.) Evaporator

$$(w_2 - w_{20} - x)\; h_b + Wh_{180^\circ} =$$

$$Wh_E + (w_2 - w_{20} - x)\; h_{E_f} + 10^\circ$$

(4.) Deaerator

$$(w_1 - w_2 - w_3 + W)\; h_i + w_3 h_c + (w_2 - w_{20} - x)\; h_{E_f} + 10^\circ +$$

$$w_{20} h_{k_f} + 15^\circ + xh_{f_f} + 10^\circ =$$

$$(w_1 + W)\; h_j$$

(5.) High Pressure Heater

$$(w_1 + W + x)\; h_{j1} + w_{20} h_b =$$

$$(w_1 + W + x)\; h_k + w_{20} h_{k_f} + 15^\circ$$

(6.) Air Ejector

$$(w_1 - w_2 - w_3 - w_4)\; h_f + \omega h_q =$$

$$(w_1 - w_2 - w_3 - w_4)\; hg + \omega hg_f + 5^\circ$$

(7.) Contaminated Evaporator

$$Fh_{ce} + xh_b =$$

$$Fh_{180} + xh_{ce_f} + 10^\circ$$

SOLUTIONS

W = Make-up = (Feedwater Flow) - (Steam Flow) = 309000 - 299000 =

10,000 LB/HR. = 3.2 %

Rated Capacity of Contaminated Evaporator is 2500 LB/HR. @ 75 psi. Abs. shell pressure since shell pressure reads 55 psi Abs. ∴ Assume $F = (\frac{55}{75}) \cdot 2500 = 1,900$ LB/HR.

EQ. (7.) $x\,(1316 - 267) = 1900\,(1176 - 148)$

$x = (1900 \cdot (1028)) \div (1149) =$
1700 LB/HR. 9th Stage Steam to contaminated evaporator

X X X X X X X X X X X X X X X X

EQ. (5.) $(309000 + 1700)\,(321.5 - 236.5) = (1316 - 339.5)\,w_{20}$

$w_{20} = ((310700)(85)) \div (976.5) =$
27000 LB/HR 9th Stage Steam to high pressure heater

X X X X X X X X X X X X X X X X

EQ. (3.) $(w_2 - 27000 - 1700) = ((10000) \cdot (1165 - 148)) \div (1316 - 233.5)$

$(w_2 - 2700 - 1700) = (10000 \cdot (1017)) \div (1082.5) = 9400$

$w_2 = 9400 + (27000 + 1700) = 38,000$ LB/HR
9th Stage Steam (Total) Extracted

X X X X X X X X X X X X X X X X

EQ. (4.) $(309000 - 38000 - w_3) \cdot (194) = 309000\,(234) - 1241\,w_3 - 9400\,(234) - 27000\,(340) - 1700\,(267)$

$271000\,(194) - 194w_3 = 72,300,000 - 1241\,w_3 - 220,000 - 9,180,000 - 454,000$

$1047\,w_3 = 72,300,000 - 62,354,000 = 9,946,000$

$w_3 = 9,500$ LB/HR. 13th Stage Steam Extracted

EQ. (1.) $(299000 - 38000 - 9500)(80 - 182) + w_4 (182 - 80) = 10000 (189 - 204) + w_4 (189 - 1137)$

$1050\ w_4 = 251500 (182 - 80) - 10000 (204 - 189)$

$1050\ w_4 = 25,600,000 - 150,000 = 25,450,000$

$w_4 = 24200$ LB/HR. 16th Stage Steam Extracted

X X X X X X X X X X X X X X X X

EQ. (6.) $(299000 - 38000 - 9500 - 24200) (80 - 76) = \omega (1455 - 85)$

$1370\ \omega = 227,300 (4) = 909,200$

$\omega = 670$ LB/HR. Steam to Air Ejectors

X X X X X X X X X X X X X X X X

Condenser Flow $= w_1 - w_2 - w_3 - w_4 - \omega$

$= 299000 - 38000 - 9500 - 24200 - 700 = 299000 - 72400$

Condenser Flow = 226,600 LB/HR.

NO. 1 Boiler Efficiency

$$(\eta_B)_1 = \frac{\text{Heat Output}}{\text{Heat Input}} = \frac{1455 (158000) - (321.5) (163000)}{18500 (11140)} =$$

$$\frac{(230 - 52.3) \times 10^6}{(18500)\ 11140} = \frac{177.7 \times 10^6}{(18500)\ 11140} = 86.4\%$$

NO. 2 Boiler Efficiency

$$(\eta_B)_2 = \frac{1455 (141000) - 321.5 (146000)}{18500 (10420)} = \frac{(205 - 46.9) \times 10^6}{18500 (10420)} =$$

$$\frac{158.1 \times 10^6}{18500 (10420)} = 82.1\%$$

Average Overall Boiler Efficiency

$$(\eta_B) = \frac{1455 (299000) - 321.5 (309000)}{18500 (21560)} = \frac{(435 - 99.4) \times 10^6}{18500 (21560)} =$$

$$\frac{335.6 \times 10^6}{18500 (21560)} = 84.3\%$$

X X X X X X X X X X X X X X X X

Heat leaving boilers = (Heat in steam) + (Heat in blowdown) +
(Heat lost)

Heat entering boilers = (Heat in fuel) + (Heat in feedwater)

Heat leaving boilers = (1455 (299000)) + (529 (10000)) +
(0.157) (18500 x 21560) =

(435,000,000) + (5,200,000) + (62,500,000)=
502,700,000 BTU/HR.

Heat entering boilers = ((18500)(21560)) + ((321.5) (309000)) =

398,500,000 + 99,400,000 = 497,900,000 BTU/HR.

The calculated values of heat entering and of leaving check within 0.95%

X X X X X X X X X X X X X X X X

Air supplied per hour = (166000 + 152000) = 318,000 LB/HR.

$$\text{Air used} = \frac{318000 \text{ LB AIR/HR.}}{21560 \text{ LB FUEL/HR.}} = 14.8 \text{ LB AIR/ LB FUEL} \qquad \text{BOTH BOILERS}$$

$$\text{AIR USED} \quad \text{NO. 1 BOILER } \frac{166000}{11140} = 14.9 \text{ LB AIR/ LB FUEL}$$

$$\text{AIR USED} \quad \text{NO. 2 BOILER} = \frac{152000}{10420} = 14.6$$

Assuming the English furnace oil, the heating value of which is 18,500 BTU/LB., is similar in ultimate analysis to California oil:

% Carbon	% Hydrogen	% Oxygen & Nitrogen	% Sulfur
81.52	11.51	6.92	0.55

$$\text{Theoretical air} = 11.5\,(c) + 34.5\,(H - \frac{O}{8}) + 4.3\,(s)$$

$$\text{Theoretical air} = 11.5\,(.8152) + 34.5\,(0.1151 - \frac{0.0692}{8}) + 4.3\,(0.0055)$$

$$= 9.38 + 3.68 + .0237 = 13.08 \text{ LB AIR/LB FUEL}$$

EXCESS AIR $= \frac{14.8}{13.08} - 1 = 1.13 - 1 = 0.13 = 13\%$ Excess Air

NO. 1 EXCESS AIR $= \frac{14.9}{13.08} - 1 = 14\%$

NO. 2 EXCESS AIR $= \frac{14.6}{13.08} - 1 = 11.5\%$

X X X X X X X X X X X X X X X X

Heat recirculated by air preheater

ASSUME: Specific Heat of Air = 0.24 BTU/ LB°F

Heat recirculated = 318000 ($T_{out} - T_{in}$) x 0.24 = 318000 (375 - 50)(0.24)

Heat recirculated = 24,800,000 BTU/HR.

X X X X X X X X X X X X X X X X

Heat given up by turbine steam from:

Inlet to 9th stage	(1455 - 1316)(299000 - 670) =	41.5×10^6 BTU/HR.
9th stage to 13th stage	(1316 - 1241)(298300 - 38000) =	19.5×10^6
13th stage to 16th stage	(1241 - 1137)(260300 - 9500) =	26.1×10^6
16th stage to condenser	(1137 - 1020)(250800 - 24200) =	26.5×10^6
TOTAL		113.6×10^6
GENERATOR OUTPUT	(31050)(3412)	$=105.8 \times 10^6$
Mechanical & Electrical losses		7.8×10^6 BTU/HR.

HEAT RATE

$$H.R. = \frac{(1455(299000) - 321.5\ (309000)\ )\ BTU/HR}{31050\ K.W.} =$$

$$\frac{(435 - 99.4) \times 10^6}{31050} = \frac{335.6}{31050} \times 10^6$$

HEAT RATE = 10,780 BTU/H.W. - HR.

X X X X X X X X X X X X X X X X

REGENERATIVE CYCLE EFFICIENCY

$$\eta_{\text{REG.}} = \frac{\left\{(w_1 - \omega)(h_a - h_b) + (w_1 - \omega - w_2)(h_b - h_c) + (w_1 - \omega - w_2 - w_3)(h_c - h_d) + (w_1 - \omega - w_2 - w_3 - w_4)(h_a - h_e) - AW_{pump}\right\}}{(w_1 - \quad)(h_a - h_k) - AW_{pump}}$$

$$\eta_{\text{REG.}} = \frac{41.5 + 19.5 + 26.1 + 26.5 - AW_{pump}}{(298300)(1455 - 321.5) - AW_p} = \frac{113.6 \times 10^6 - AW_{pump}}{(298300)(1133.5) - AW_p}$$

BOILER FEED PUMP = 361 H.P.)
) TWO OF EACH PUMP $W_{pump} = 2(391) = 782$ H.P.
CONDENSATE PUMP = 30 H.P.)

$$AW_{pump} = 782 \times \frac{33000}{778} \text{ BTU/MIN.} = 782 \times \frac{(33000)}{(778)} 60 = 1.99 \times 10^6 \text{ BTU/H}$$

$$\eta_{\text{REG.}} = \frac{(113.6 - 2) \times 10^6}{(298300)(1133.5) - 1.99 \times 10^6} = 33.2\%$$

X X X X X X X X X X X X X X X X

GENERATOR EFFICIENCY

$\eta_g = 98.2\%$ FROM FIG. 260 OF "POWER PLANT ENGINEERING AND DESIGN" BY F. T. MORSE

X X X X X X X X X X X X X X X X

OVERALL THERMAL EFFICIENCY

$$\eta_{AO} = \frac{3412}{\text{BTU.STEAM/KW.-HR.}} = \frac{3412}{10780} = 31.7\%$$

X X X X X X X X X X X X X X X X

ACTUAL THERMAL EFFICIENCY

$$\eta_A = \frac{\eta_{AO}}{\eta_g} = \frac{31.7}{98.2} = 32.2\%$$

X X X X X X X X X X X X X X X X

MECHANICAL EFFICIENCY

$$\eta_M = \frac{\eta_A}{\eta_{REG}} = \frac{32.2}{33.2} = 97.0\%$$

$$\eta_M \eta_g = \frac{\text{Generator Output}}{\Sigma \text{Heat given up in stages}} = \frac{105.8 \times 10^6}{113.6}$$

$$\eta_M \eta_g = 93.2\%$$

$$\eta_M = \frac{93.2}{\eta_g} = \frac{93.2}{98.2} = 95.0\%$$

X X X X X X X X X X X X X X X X

OVERALL PLANT EFFICIENCY

$$(\eta_o)_{Gross} = \frac{\text{Gross output at switchboard}}{\text{Input from fuel oil}} = \frac{(31050)(3412)}{(18500)(21560)} = 26.6\%$$

$$(\eta_o)_{Net} = \frac{\text{Net output at switchboard}}{\text{Input from fuel}} = \frac{29800\ (3412)}{18500\ (21560)} = 25.5\%$$

X X X X X X X X X X X X X X X X

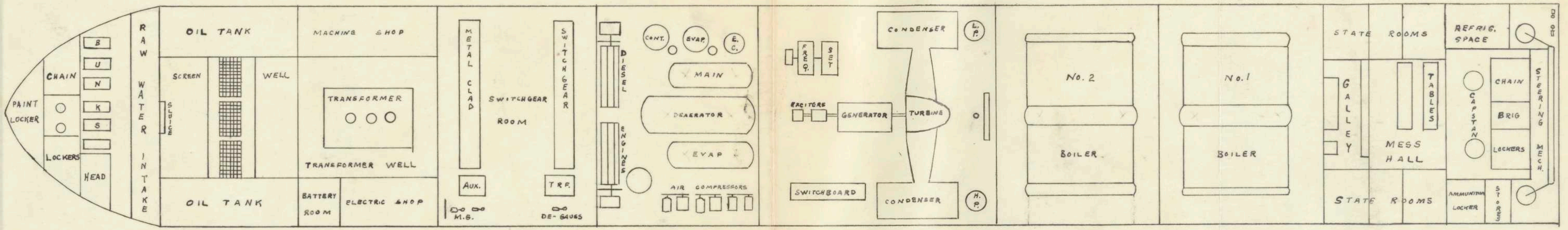
POUNDS OF FUEL PER KILOWATT - HOUR (GROSS)

$$\frac{21560 \text{ LB.FUEL/HR.}}{31050 \text{ K.W. Gross}} = 0.693 \text{ LB FUEL/K.W.H.}$$

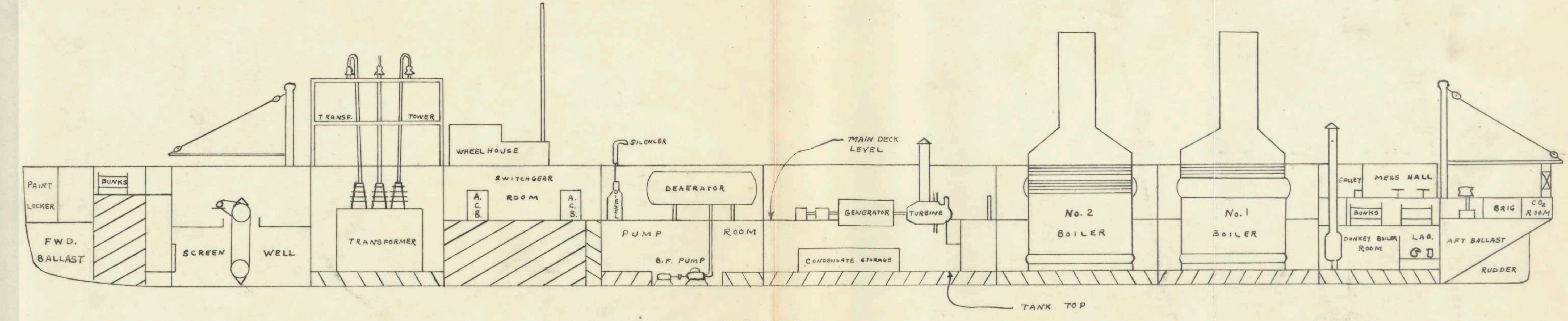
X X X X X X X X X X X X X X X X

POUNDS OF FUEL PER KILOWATT - HOUR (NET)

$$\frac{21560 \text{ LB.Fuel/HR.}}{29800 \text{ K.W. Net}} = 0.723 \text{ LB.FUEL/K.W.H.}$$

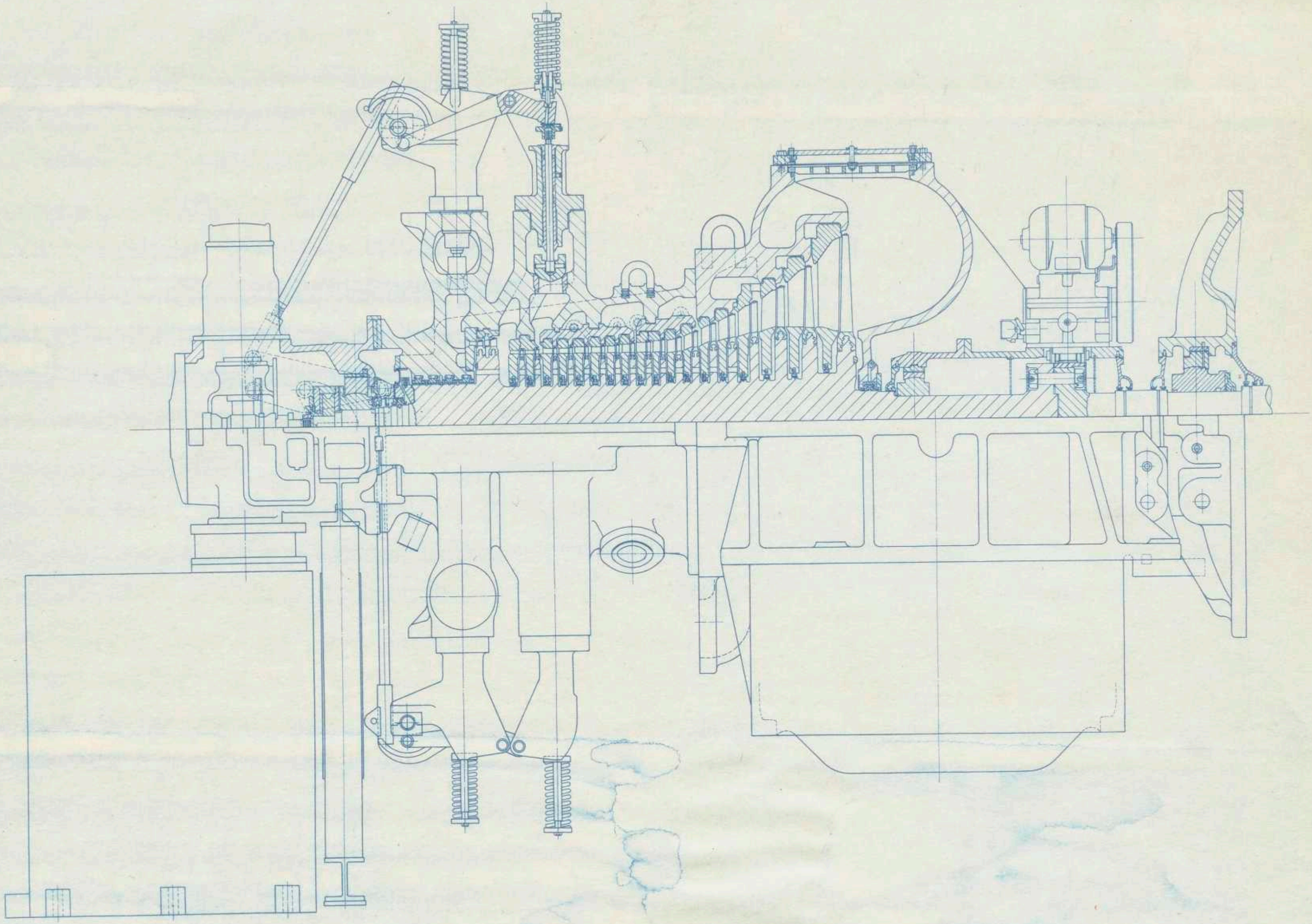


PLAN



ELEVATION

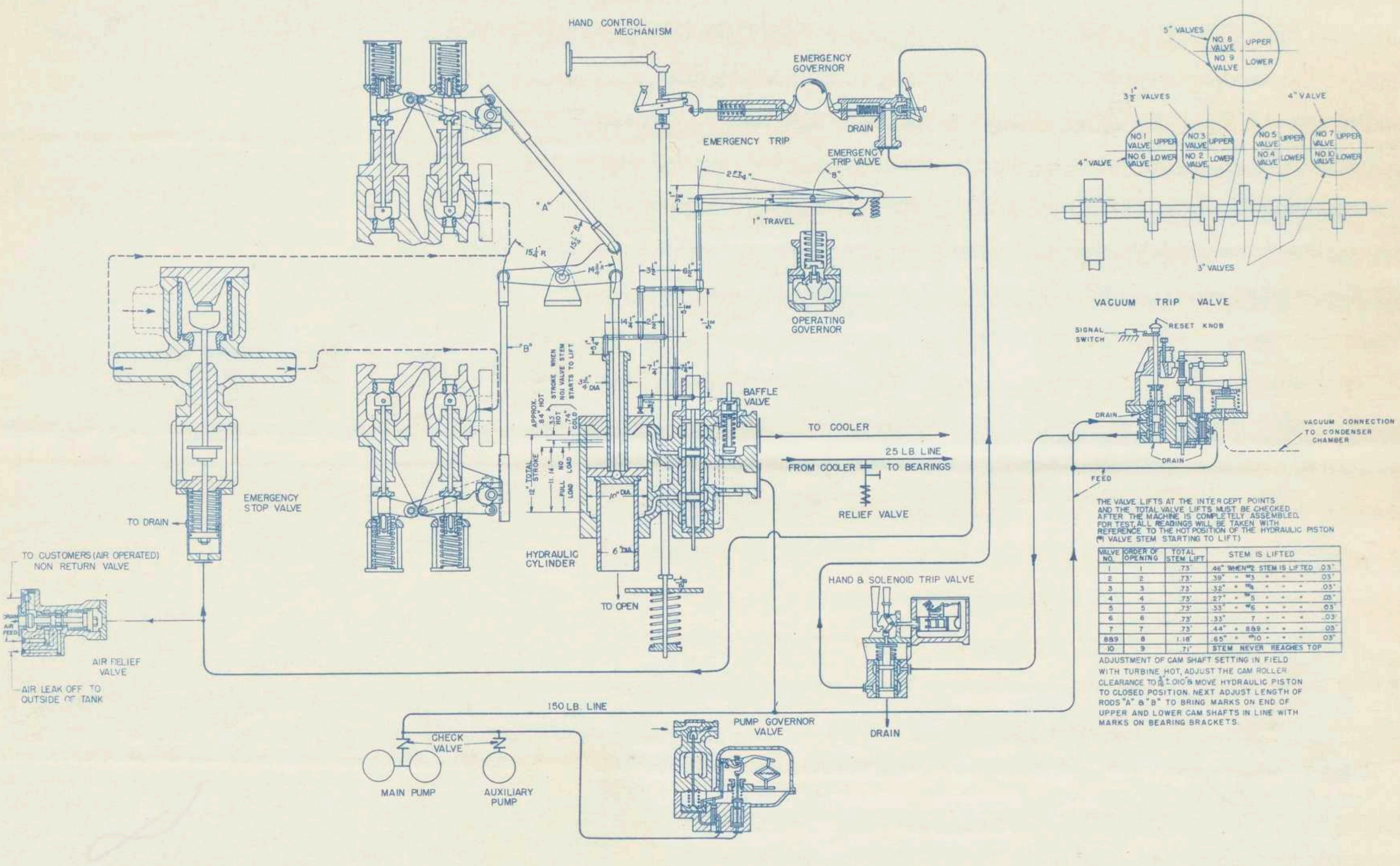
Fig. 1 FLOATING POWER PLANT



593093 G-E STEAM TURBINE, 30,000 KW, 3600 RPM, 19-STAGE, LONGITUDINAL SEMISECTION, DRG. W-8679013. FOR FLOATING POWER PLANT.

FILING NO.400 E165.22 1-7-43

FIG. 2



THE VALVE LIFTS AT THE INTERCEPT POINTS AND THE TOTAL VALVE LIFTS MUST BE CHECKED AFTER THE MACHINE IS COMPLETELY ASSEMBLED. FOR TEST, ALL READINGS WILL BE TAKEN WITH REFERENCE TO THE HOT POSITION OF THE HYDRAULIC PISTON (#1 VALVE STEM STARTING TO LIFT)

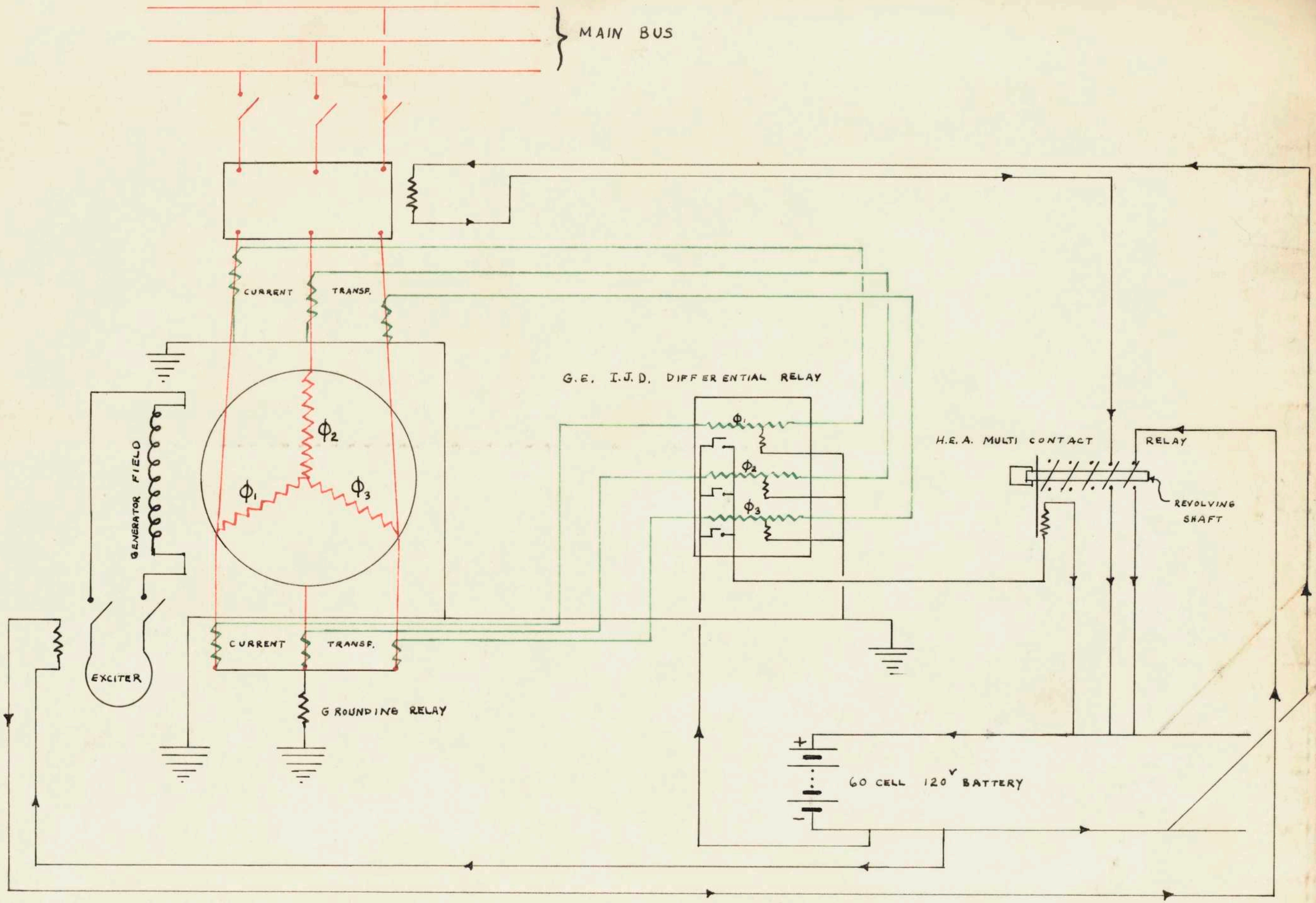
VALVE NO.	ORDER OF OPENING	TOTAL STEM LIFT	STEM IS LIFTED
1	1	.73"	.46" WHEN #2 STEM IS LIFTED .03"
2	2	.73"	.39" " #3 " " " .03"
3	3	.73"	.32" " #4 " " " .03"
4	4	.73"	.27" " #5 " " " .03"
5	5	.73"	.33" " #6 " " " .03"
6	6	.73"	.33" 7 " " " .03"
7	7	.73"	.44" " 889 " " " .03"
889	8	1.18"	.65" " #10 " " " .03"
10	9	.71"	STEM NEVER REACHES TOP

ADJUSTMENT OF CAM SHAFT SETTING IN FIELD WITH TURBINE HOT, ADJUST THE CAM ROLLER CLEARANCE TO 3/16" ± .010" & MOVE HYDRAULIC PISTON TO CLOSED POSITION. NEXT ADJUST LENGTH OF RODS "A" & "B" TO BRING MARKS ON END OF UPPER AND LOWER CAM SHAFTS IN LINE WITH MARKS ON BEARING BRACKETS.

592508 CONTROLLING MECHANISM FOR G-E STEAM TURBINE, 30,000 KW, 3600 RPM, 19-STAGE.
SCHEMATIC DIAGRAM WITH PARTS NAMED, DRG. T-8252186. FOR FLOATING POWER PLANT.

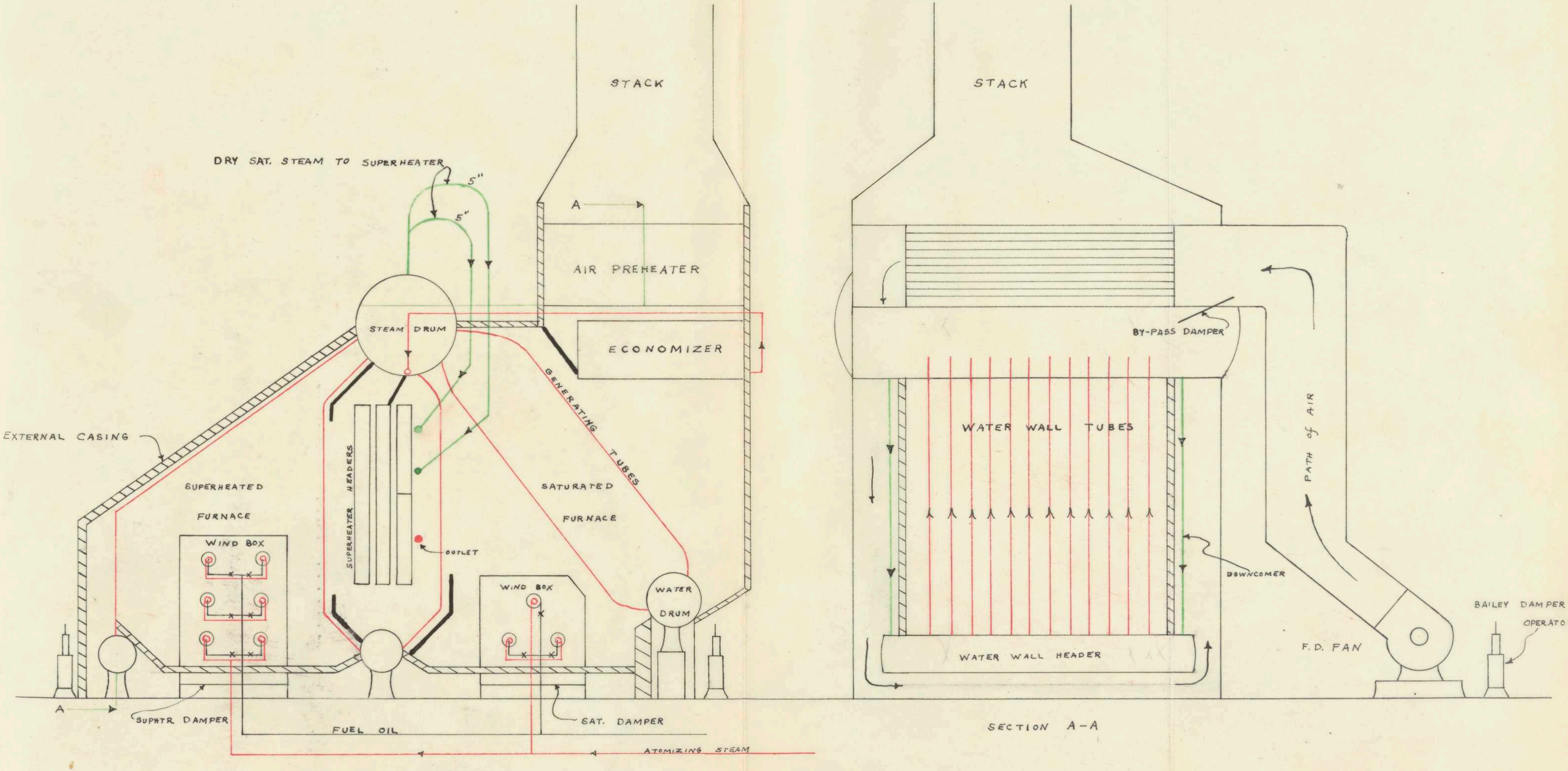
FILING NO.400 E165.35 11-17-42

FIG. 3



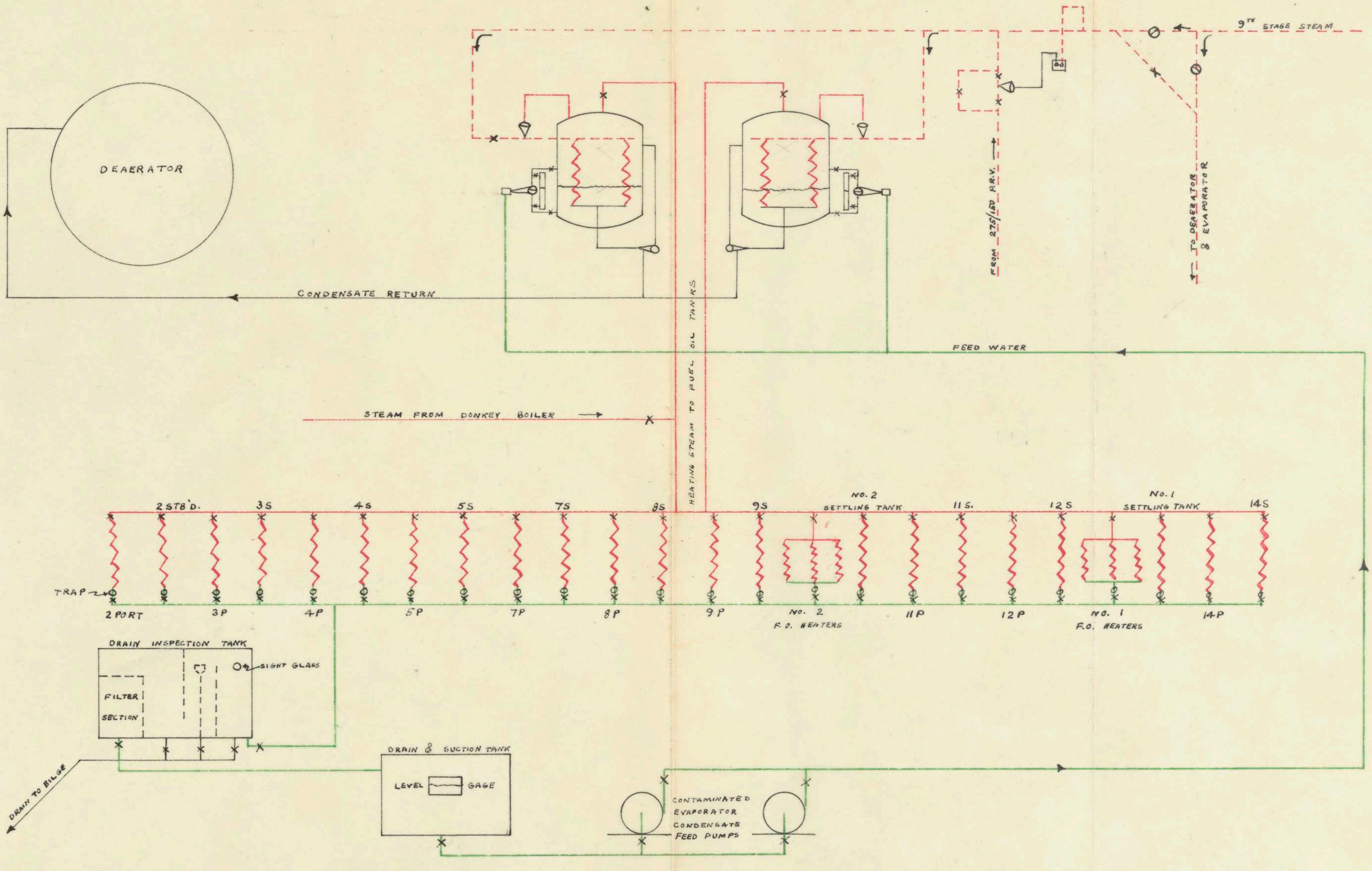
GENERATOR PROTECTION

FIG. 4



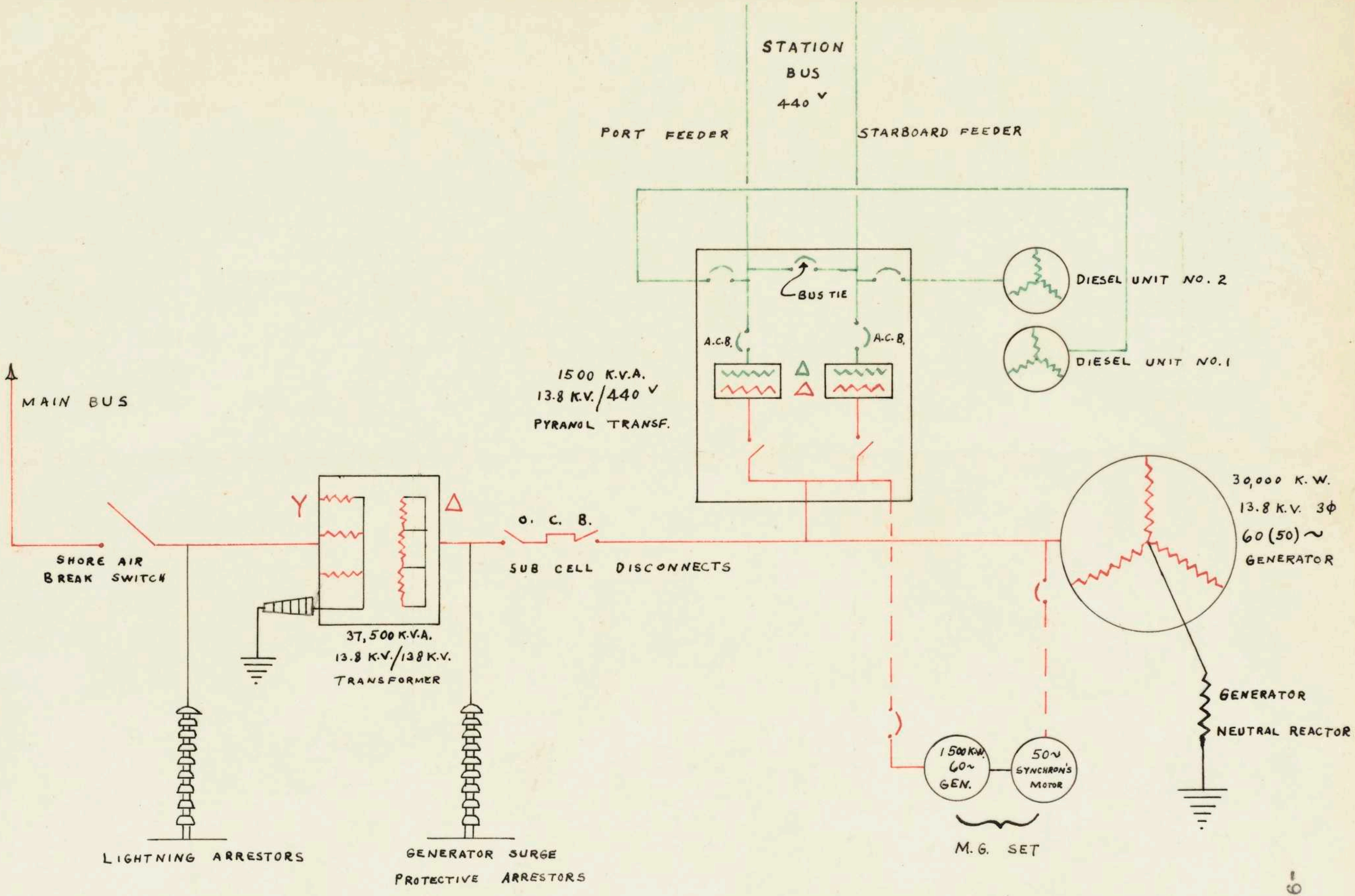
B. & W. MARINE EXPRESS TYPE BOILER

FIG. 5



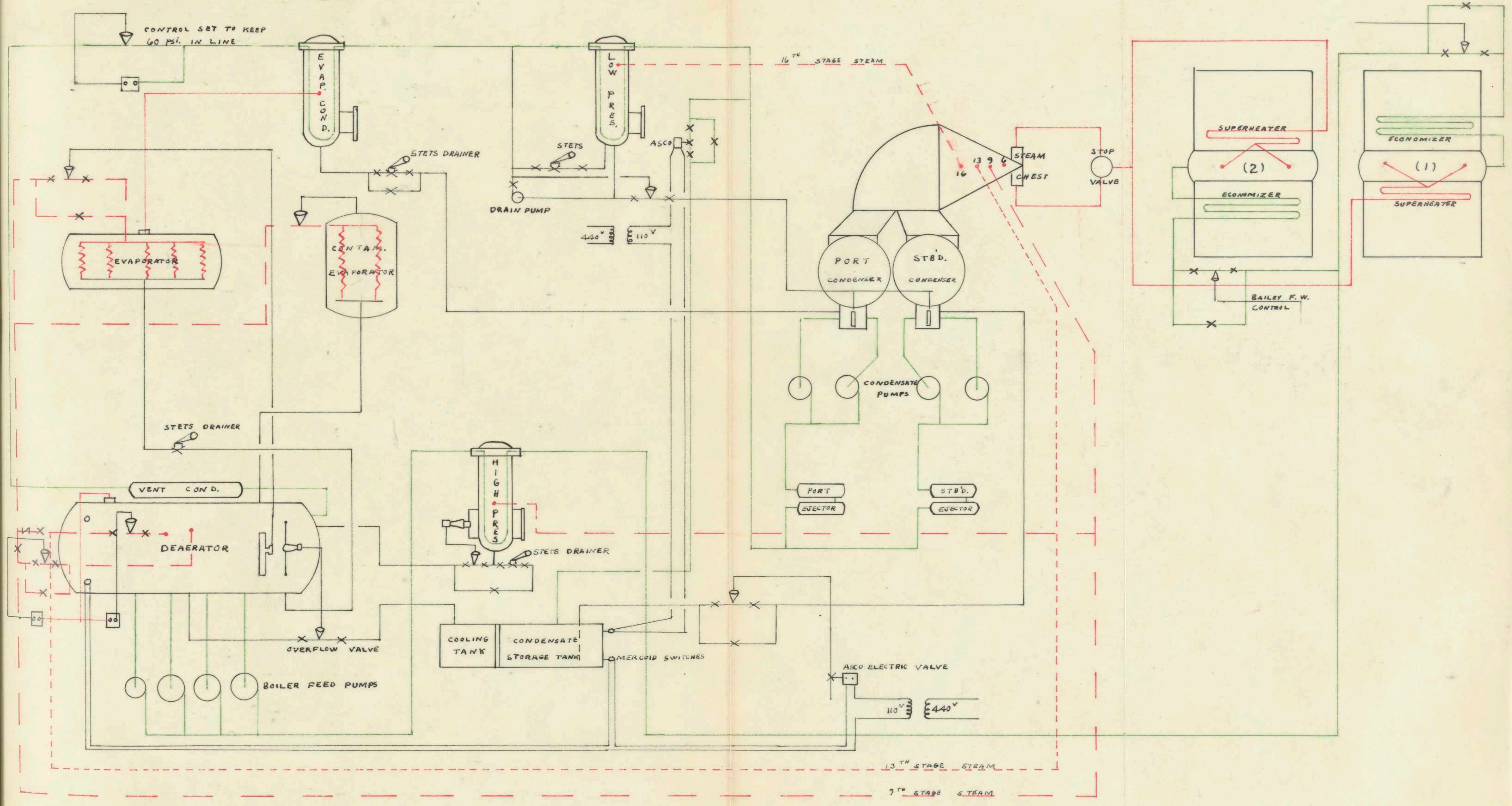
CONTAMINATED EVAPORATORS

FIG. 6



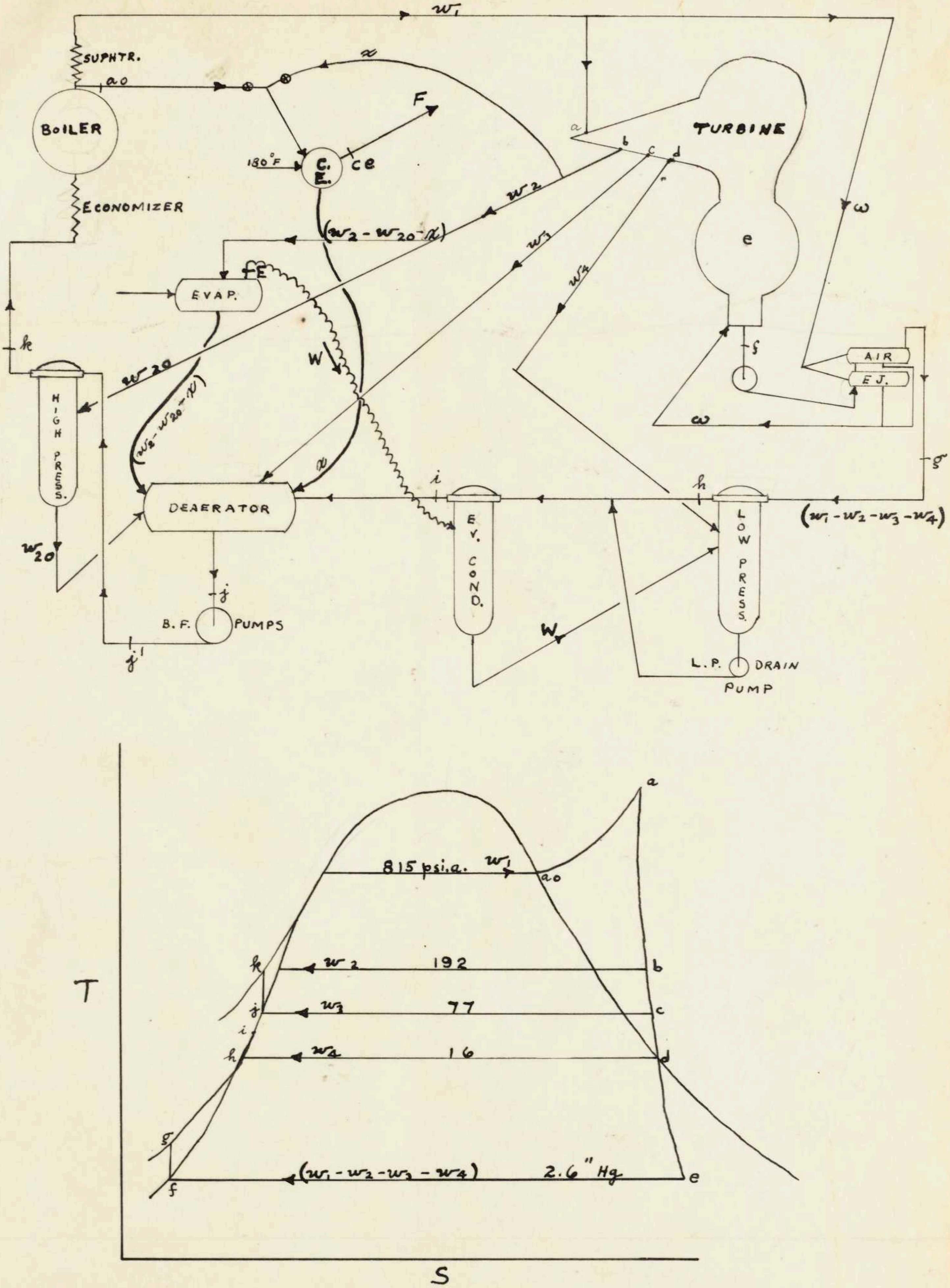
MAIN & STATION BUS

FIG. 7



FLOW DIAGRAM

FIG. 8



SCHEMATIC DIAGRAMS for CALCULATIONS

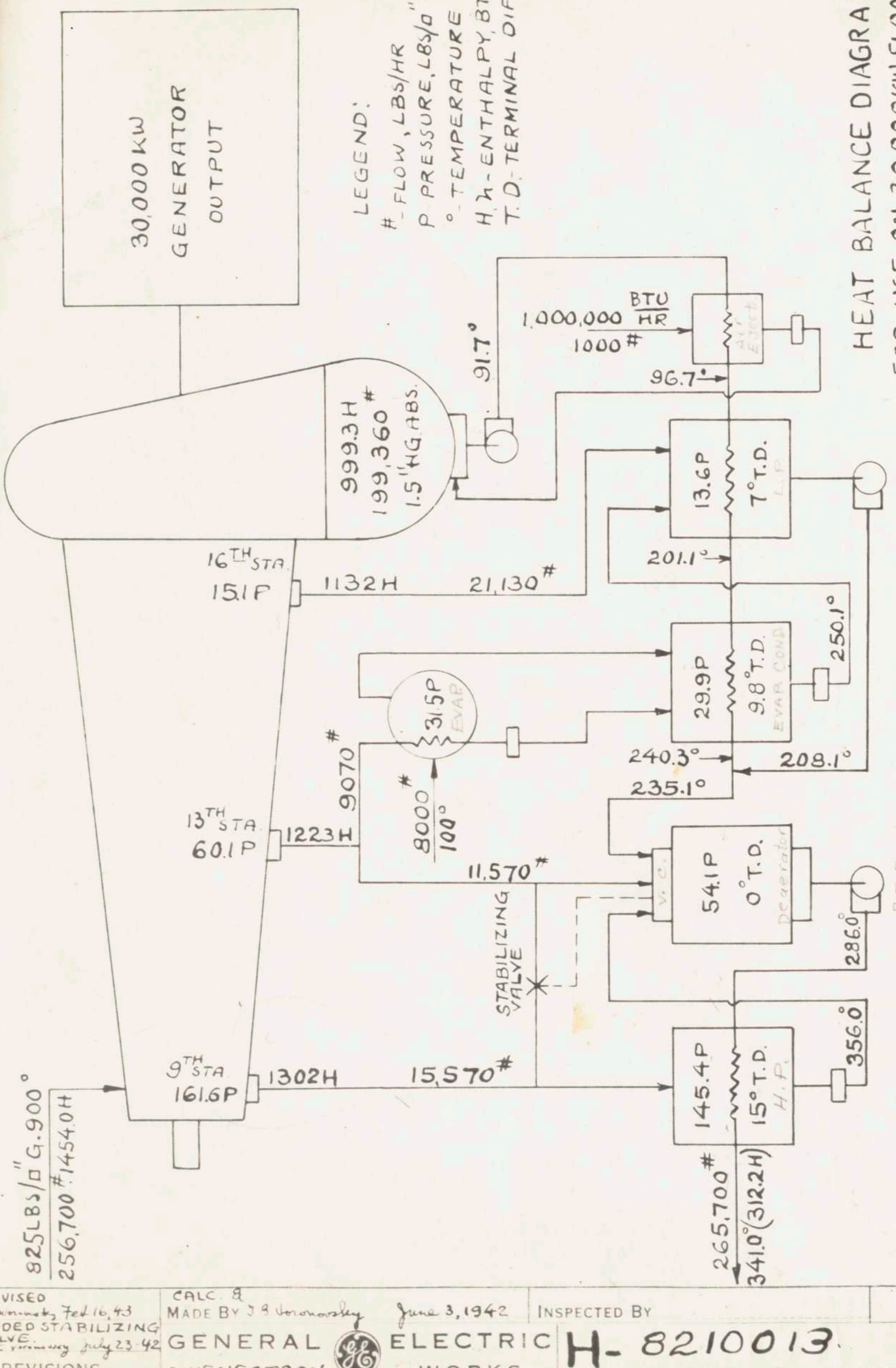
FIG. 9

THIRD ANGLE PROJECTION

H-8210013

HEAT BALANCE DIAGRAM

FOR USE ON 30,000KW FLOATING
POWER PLANT OF DEFENSE
PLANT CORP. PLANCOR 525
GIELOW INC. ENG. & CONTRACTORS



LEGEND:
- #- FLOW, LBS/HR
- P- PRESSURE, LBS/□" ABS.
- °- TEMPERATURE
- H, h- ENTHALPY, BTU/LB
- T.D.- TERMINAL DIFF.

$$\text{BTU RATE} = \frac{256,700 \times (1454.0 - 312.2)}{30,000} = 9770$$

REVISED
Voronovsky Feb 16, 43
ADDED STABILIZING VALVE.
Voronovsky July 23-42
REVISIONS

CALC. &
MADE BY J. S. Voronovsky June 3, 1942

INSPECTED BY

GENERAL ELECTRIC
SCHENECTADY WORKS

H-8210013

SHEET NO. CONT. ON SHEET

PRINTS TO

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