

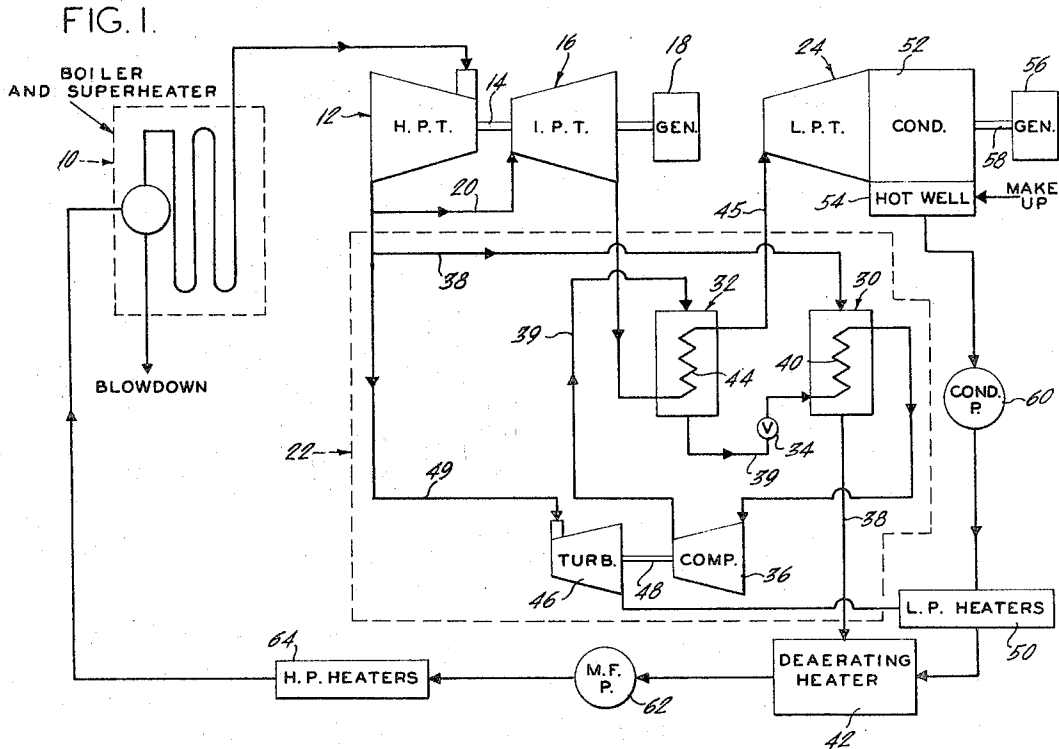
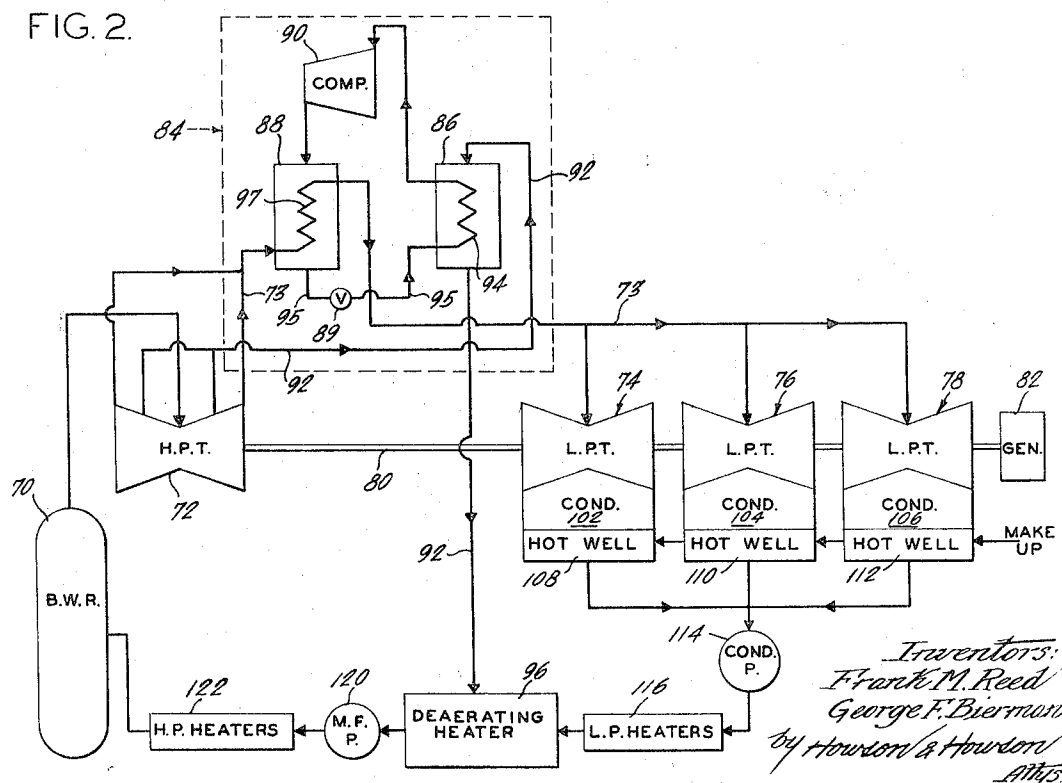
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REHEAT CYCLE FOR STEAM TURBINE POWER PLANTS

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REHEAT CYCLE FOR STEAM TURBINE POWER PLANTS

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4 Claims. (Cl. 60—73)

This invention relates to a steam turbine power plant, and more specifically, to a self-contained reheat cycle for reheating expanded steam in the steam path between turbine stages of a steam turbine power plant.

In recent years the use of higher steam pressures has necessitated reheating of steam in the steam path between steam turbine stages. This, in turn, has forced the adoption of larger single boiler units because of the complexity of the boiler reheat connections. As the boiler unit has increased in size, there has been a corresponding increase in fuel and operating efficiency. However, there is at the same time a greater chance of operating failure of the boiler due to the necessarily increased length of reheat tubing in the reheat section. In fact the operating failures have more than offset gains in efficiency by increasing the amount of time the boiler has to be out of operation for repair and maintenance.

In accordance with the present invention, the reheat section of the boiler is eliminated thereby eliminating as well its reheat piping, connections, fittings and valves. The elimination of the boiler reheat section also increases fuel efficiency since that part of the heat of the fuel used in reheating can be used in the main boiler function. Reheating is instead accomplished by a heater heated by working steam bled from the steam path and connected to reheat the steam passing between the different ones of the steam turbines in the steam path. Such a system by elimination of the reheat makes possible use of a larger number of available types of boilers since the custom made aspect of multiple connections imposed by the complexity and individuality of boiler reheat systems are eliminated. The reheating energy necessary to reheat the steam in accordance with the present invention is obviously as great as it is in prior art boiler reheat systems and in fact overall operating efficiencies will undoubtedly be slightly less with the present invention. However, considering "down time" of more complex equipment and its cost, the system of the present invention proves more economical. The system of the present invention is particularly useful in connection with a turbine fed from a nuclear steam generator, as it eliminates the necessity of superheating or reheating by fossil fuel or the complication of superheating or reheating by steam in the nuclear generator itself.

The steam turbine power plant of the present invention comprises a boiler including a steam generating portion connected in a steam path and a plurality of steam turbines connected in the steam path. The reheat feature of the present invention is provided by reheater means connected between different ones of the steam turbines in the steam path. The working steam passing through the reheater means between the steam turbines is heated by steam bled from the steam path, thereby imparting additional energy to the steam.

Preferably, there are two heaters employed in the reheater means connected in a closed cycle steam system. A first heater receives heat from steam bled from the steam path and transfers heat from that steam to steam in the closed cycle circuit which includes a second heater. The heat from the steam in the closed cycle circuit in passing through the second heater transfers heat to steam in the steam path between the steam turbines. Ordinarily, the closed cycle also includes a compressor in the path

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between the first and second heaters and a throttling means in the path from the second heater back to the first heater.

These and other features and advantages of the present invention will become more readily apparent from a consideration of the following detailed description, taken in connection with the accompanying drawings, in which:

FIGURE 1 is a schematic diagram of a steam turbine power plant embodying one form of the present invention; and

FIGURE 2 is a schematic diagram of another steam turbine power plant employing the present invention.

Referring now to the embodiment of the invention illustrated in FIGURE 1, there is represented a boiler, generally designated 10, which is of a conventional type having evaporating and superheating portions. The boiler has a connection for blow down to periodically clean the boiler. The main steam line from the boiler runs to the first stage in a series of turbine stages. The first stage comprises a high pressure turbine 12. High pressure turbine 12 drives a common shaft 14 with an intermediate pressure turbine 16 to operate a generator 18. The partially-expanded exhaust steam from the high pressure turbine is fed through the main steam line 20 to be used to drive the intermediate pressure turbine 16.

The heat balance of the conventional turbine power plant is such that the superheat imparted to the steam in the boiler is sufficient to bring the steam through the high pressure turbine and the intermediate pressure turbine without undue condensation or in virtually saturated condition and that the reheating of the steam is required only to carry the steam through the low pressure turbine. For purposes of illustration of the present invention, reheater means, generally designated 22, is shown between the intermediate pressure turbine 16 and the low pressure turbine 24.

The reheater means 22 shown in FIGURE 1 comprises a first heater 30, a second heater 32, a restriction, such as expansion valve 34, and a compressor 36. Steam is bled from the main steam line 20 containing partially-expanded steam from the output of the high pressure turbine, and the bled steam passes into steam line 38. Heater 30 is a heat exchanger having a coil 40 in a closed cycle steam route 39. The steam in coil 40 receives heat by transfer through the coil walls from the partially-expanded steam from the high pressure turbine passing in steam line 38 through heater 30 outside the coil. Steam line 38 is continued after heater 30 to carry the partially-expanded steam to deaerating heater 42. The heater 30 functioning as a heater exchanger heats steam passing through coil 40 of heater 30. The elements in the closed cycle circuit are connected by sections of steam route 39. Steam from coil 40 flows through route 39 to compressor 36, which raises the pressure and temperature of this steam to a point that will cause heat transfer in heater 32, to which steam passes from the compressor 36 through another section of route 39.

The closed cycle steam is outside coil 44 in heater 32. Through coil 44 passes the expanded steam from intermediate pressure turbine 16 on its way to low pressure turbine 24 through line 45 of which coil 44 is a part. The working steam passing through coil 44 is heated by the steam in the closed cycle steam route 39, which causes heating through coil 44 in heater 32 to heat the working steam passing in line 45 between the intermediate and low pressure turbines. Thus, the working steam is reheated to the required temperature to allow it to expand through the low pressure turbine releasing greater amounts of energy and without undue condensation.

The steam circulating the reheat suction in the steam route 39 passes through expansion valve 34 located in the return path between heater 32 and heater 30. Ex-

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ansion valve 34 provides a pressure drop in the steam route such that the temperature and pressure conditions of the closed cycle steam passing through coil 40 is reduced to a level to enable this steam to absorb heat by transfer from the partially-expanded steam passing through the heater in steam line 38, thereby allowing the reheat steam to receive maximum energy from steam in steam line 38.

For the best control to provide the most economical output at all turbine loadings, the expansion valve 34 should be thermostatically controlled to hold the temperature of reheat steam entering coil 40 to a temperature slightly below that of the partially-expanded steam passing through heater 30, and the speed of the compressor should be thermostatically controlled to provide a temperature to the steam entering heater 32 that will cause transfer of sufficient heat to the working steam in coil 44 in heater 32 to give its desired superheat to the working steam entering the low pressure turbine.

It should be observed that the heater 30 supplies most of the heat required to heat the reheat steam circulating in steam route 39 to reheat the working steam passing between the intermediate pressure turbine and the low pressure turbine. The heat supplied in heater 30 will be supplemented by the energy and temperature rise obtained in compressor 36.

The driving means for compressor 36 could be a hydraulic drive from the main turbine shaft or by another turbine 46, as shown in FIGURE 1, driving the compressor shaft 48. Turbine 46 is shown driven by steam in steam line 49 bled from steam line 38, the steam in steam line 49 being exhausted into low pressure heaters 50.

The reheated working steam passing from heater 32 into low pressure turbine 24 is exhausted from the low pressure turbine into condenser 52 and then into hot well 54, where additional make-up water is added. The low pressure turbine drives generator 56 through shaft 58. The water from the hot well passes to condenser pump 60 and then into the low pressure heaters 50. The water from low pressure heaters 50 is pumped into the deaerating heater 42, where it is combined with the steam from steam line 38, which passed through the reheat section to supply heat to coil 40 of heater 30. The water from the deaerating heater 42 passes to the main feed pump 62, from which it is pumped at a high pressure through high pressure heaters 64 and then returned to boiler 10 for recirculation through the system.

All of the components contained in the reheat section of the present invention are similar to those in general use in industry and are therefore economically available. Moreover, in this system they operate below temperatures and pressures sometimes exacted in other uses so that specifications need not be exacting.

FIGURE 2 schematically illustrates the use of the reheat means of the present invention in a nuclear steam turbine power plant. The system illustrated shows a nuclear boiler, generally designated 70, having a boiling water reactor to supply steam to a high pressure turbine 72 connected in steam line 73 in series with the boiler and in series with three parallel-connected low pressure turbines 74, 76 and 78 connected in steam line 73. The turbines are connected by a common shaft 80 to supply the driving motion for generator 82. In FIGURE 2 the reheater means, generally designated 84, is located along the main steam line 73 between the high pressure turbine and the low pressure turbines.

The reheater means 84 in FIGURE 2 comprises a first heater 86, a second heater 88, a restriction, such as expansion valve 89, and a compressor 90. The reheater means 84 in FIGURE 2 functions in the same manner as described in regard to the reheat section in FIGURE 1.

Steam is bled from the high pressure turbine 72 at tap-off points in the high pressure turbine, and the bled steam

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passes into steam line 92. Heater 86 is a heat exchanger having a coil 94 is a closed cycle steam route 95. The steam in coil 94 receives heat by transfer through the coil walls from the bled steam from the high pressure turbine passing in steam line 92 through heater 86 outside the coil. Steam line 92 is continued after heater 86 to carry the bled steam to deaerating heater 96. Heater 86 functioning as a heat exchanger heats steam passing through coil 94 of the heater. The elements in the closed cycle circuit are connected by sections of steam route 95. The steam in coil 94 flows through steam route 95 to compressor 90, which raises the pressure and temperature of this steam to a point that will cause heat transfer in heater 88, to which steam passes from compressor 36 through another section of steam route 95.

The closed cycle steam route is outside coil 97 in heater 88. The expanded steam in steam line 73 passes through coil 97 from high pressure turbine 72 on its way to the low pressure turbines. The working steam passing through coil 97 is heated by the steam in the closed cycle steam route 95, which causes heating through coil 97 in heater 88 to heat the working steam passing in steam line 73 between the high and low pressure turbines. Thus, the working steam is reheated to the required temperature to allow it to expand through the low pressure turbines releasing great amounts of energy.

The steam circulating in the reheat section in steam route 95 passes through expansion valve 98 located in the return path between heaters 88 and 86. Valve 89 provides a pressure drop in the steam route such that the temperature and pressure conditions of the closed cycle steam passing through coil 94 is reduced to a level to enable this steam to absorb heat by transfer from the steam passing through the heater in steam line 92, thereby allowing the reheat steam to receive maximum energy from steam in steam line 92.

Expansion valve 89 in steam route 95 between heater 88 and heater 86 should be, for best operation of the system, thermostatically regulated in order to hold the pressure and temperature of the reheat steam leaving it at a temperature below the temperature of condensation of the steam passing through heater 86 in steam line 92. Also, the speed of the compressor 90 should be thermostatically regulated in such a manner that the reheat steam delivered by the compressor to heat 88 will pass sufficient heat to coil 97 to superheat the working steam to the desired temperature before passing it through the low pressure turbines.

The compressor 90 may be steam driven from steam bled from the output of the high pressure turbine. In such a case a small water separator may be required. In some applications, steam drive for starting the compressor and a hydraulic coupling to the main shaft of the compressor for normal operation may be most satisfactory. In any event the speed of the compressor should be regulated to meet the requirements of the cycle in the reheat section under all operating conditions.

The reheated working steam in the main steam line 73 is divided into three channels for operating the low pressure turbines 74, 76 and 78. The working steam passed through the low pressure turbines 74, 76 and 78 passes into condensers 102, 104 and 106, respectively, where it is then fed into hot wells 108, 110 and 112, respectively. In the hot wells additional make-up water is added. As the water leaves hot wells 108, 110 and 112 it is recombined and passed into condenser pump 114 from which it is pumped into low pressure heaters 116. Deaerating heater 96 receives the expanded steam from steam line 92 used to heat heater 86 and also the water from low pressure heaters 116. The water of the deaerating heater is passed to main feed pump 120 and then to high pressure heaters 122. The water from the high pressure heaters is passed to the boiling water reactor 70 for recirculation through the system.

Prior to the present invention, it had not been found

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feasible to reheat steam or even superheat steam in the boiling water reactor type of nuclear boiler. However, had it been possible to reheat the steam, the same problems would have existed as outlined in the introduction of the specification in regard to the conventional boiler. Nuclear power units of the prior art require moisture separators and reheaters which acquire much of their heat supply from unexpanded steam or from fossil fuel in separate steam reheaters. This has lead to excessive recycling of the working steam through the boiler as compared to the useful work done by the steam. By the present self-contained reheat cycle, the reheating of the working steam after the steam has passed through the high pressure turbine eliminates the moisture losses and conditions the steam for efficient energy production in the low pressure turbines.

The reheat system of the present invention could, for example, be installed to reheat the turbine steam between a high pressure turbine and an intermediate pressure turbine and also between an intermediate pressure turbine and a low pressure turbine. Each reheat system would consist of a compressor, a first heat exchanger to transfer heat to the main turbine working steam, a second heat exchanger to absorb heat from the steam bled from the main steam line and supplied to the heat exchanger and a restriction. Also, other possible combinations for connecting turbines in a power plant system are possible with the reheat system connected at different points therein.

It should be understood that the reheat section of the present invention could operate with one heater connected between different ones of the steam turbines in the main steam line. The heater would be heated by the steam bled from the main steam line and heat the steam passing in the main steam line between the different ones of the steam turbines. Also, a single heater could be used as the reheat means that is heated by an outside source separate from the boiler, which generates the steam circulated in the main steam line.

From the above it will be clear that the self-contained reheat cycle of the present invention has many advantages. In particular there is an overall gain in efficiency because of less heat discharge to the condenser per unit of heat supplied by the fuel in the boiler. The system eliminates the reheat tubing in boilers and the reheat piping and connections between the boiler and turbines. By utilizing the reheat cycle of the present invention, there is a reduction in condenser water supply required per unit of output with a consequent reduction in cost of cooling water facilities. As previously stated, the reheat cycle would make feasible the use of a boiler heater system, connected to the turbines, which would in turn materially increase the selection of compatible boilers over the single-boiler single-turbine unit system currently used because of the limitation to multiple connections imposed by the complexity of the reheat piping. The net result of the present reheat cycle is to reduce materially the heat discharged to the condensing water in comparison to the total heat input from fuel. Thus, the efficiency of the boiler-turbine cycle will be improved.

While the invention has been described with particular reference to specific embodiments thereof in the interest of complete definiteness, it should be understood that it may be embodied in a large variety of forms diverse from those specifically shown and described, without departing from the scope and spirit of the invention as defined by the appended claims.

We claim:

1. A steam turbine power plant comprising:

- a steam path;
- a boiler including evaporating and superheating portions connected in and providing a part of said steam path;
- a plurality of steam turbines connected in and providing a part of said steam path;

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a steam line from said steam path for bleeding working steam from said steam path after some work has been performed by the steam in the steam path; and

reheater means connected between different ones of said steam turbines in said steam path comprising a closed cycle steam route, a first heat exchanger in said steam route and coupled to said steam line to adsorb heat from said bled steam for heating steam in said steam route, a compressor located after said first heat exchanger, a second heat exchanger located after said compressor in said steam route and coupled to said steam path for transferring heat from steam in said steam route to steam in said steam path, and a restriction located after said second heat exchanger for providing a pressure change of said steam in said steam route.

2. A steam turbine power plant comprising:

- a steam path;
- a boiler including evaporating and superheating portions connected in and providing a part of said steam path;

a plurality of steam turbines connected in and providing a part of said steam path;

a steam line from said steam path for bleeding working steam from said steam path after some work has been performed by the steam in the steam path; and

reheat means connected between different ones of said steam turbines in said steam path comprising a closed cycle steam route, a first heater in said steam route and coupled to said steam line heated by said bled steam for heating steam in said steam route, a compressor located after said first heater in said steam route, a second heater located after said compressor in said steam route and coupled to said steam path heated by said steam in said steam router for heating said steam in said steam path, and a restriction located after said second heater for providing a pressure change of said steam in said steam route.

3. A steam turbine power plant comprising:

- a steam path;
- a nuclear boiler including a boiling water reactor connected in and providing a part of said steam path;
- a plurality of steam turbines connected in and providing a part of said steam path;

a steam line from said steam path for bleeding working steam from said steam path after some work has been performed by the steam in the steam path; and reheater means connected between different ones of said steam turbines in said steam path comprising a closed cycle steam route, a first heat exchanger in said steam route and coupled to said steam line to absorb heat from said bled steam for heating steam in said steam route, a compressor located after said first heat exchanger in said steam route, a second heat exchanger located after said compressor in said steam route and coupled in said steam path for transferring heat from steam in said steam route to steam in said steam path, and a restriction located after said second heat exchanger in said steam route for providing a pressure change of said steam in said steam route.

4. A steam turbine power plant comprising:

- a steam path;
- a nuclear boiler including a boiling water reactor connected in and providing a part of said steam path;
- a plurality of steam turbines connected in and providing a part of said steam path;

a steam line from said steam path for bleeding working steam from said steam path after some work has been performed by the steam in the steam path; and reheater means connected between different ones of said steam turbines in said steam path comprising a closed cycle steam route, a first heater in said steam route and coupled to said steam line heated by said

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bled steam for heating steam in said steam route, a compressor located after said first heater in said route, a second heater located after said compressor in said steam route and coupled to said steam path heated by steam in said steam route for heating steam in said steam path, and a restriction located after said second heater in said steam route for providing a pressure change of said steam in said steam route.

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