

April 2, 1963

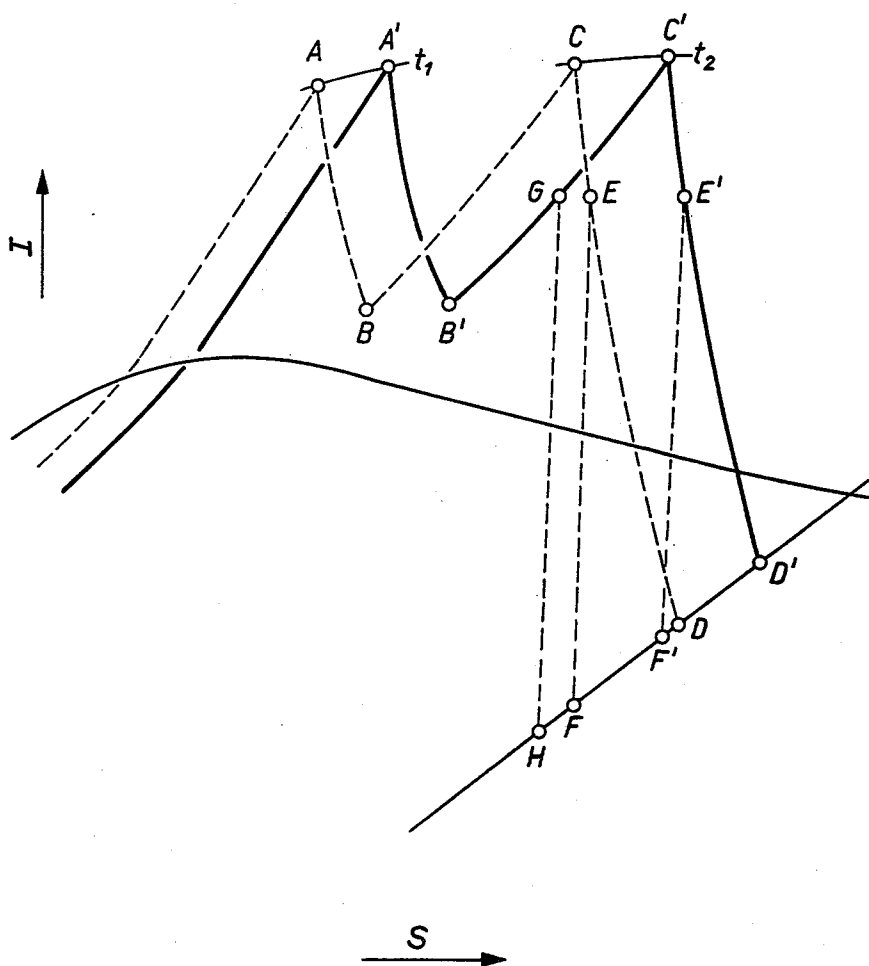
H. VOGLER
APPARATUS FOR OPERATING A STEAM POWER PLANT
INCLUDING A REHEATER AND TAPPED STEAM
OPERATED STEAM CONSUMERS

3,083,536

Filed Dec. 20, 1960

4 Sheets-Sheet 1

Fig. 1



Inventor:
HANS VOGLER.
By K. A. Mayr.
Attorney:

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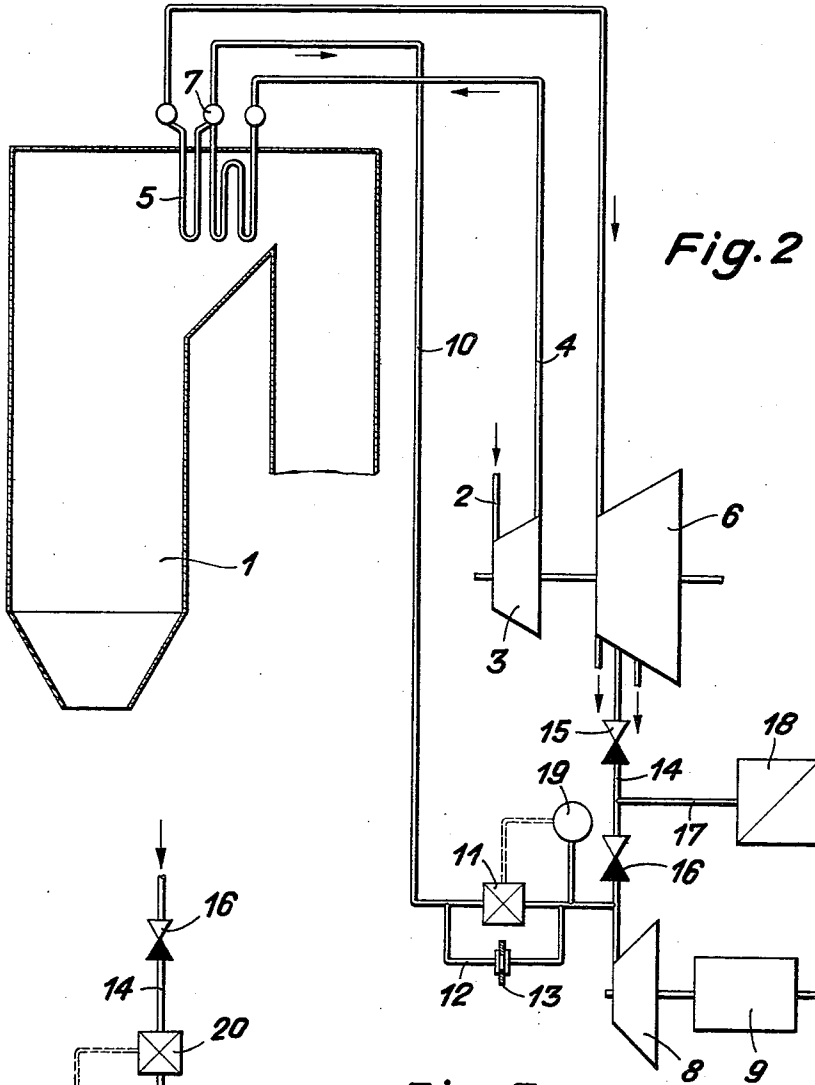


Fig. 2

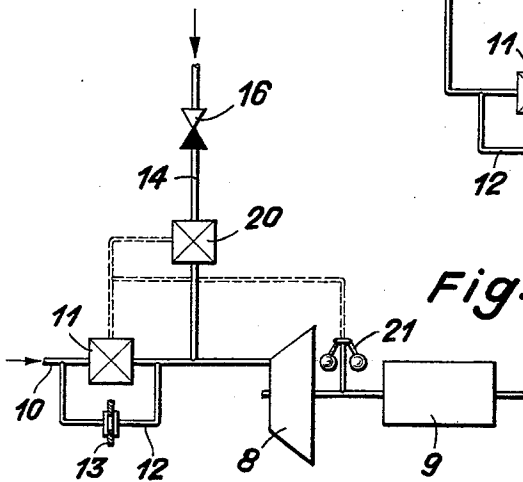


Fig. 3

Inventor:
HANS VOGLER.
By K. A. Mayr
Attorney.

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By K. A. May:
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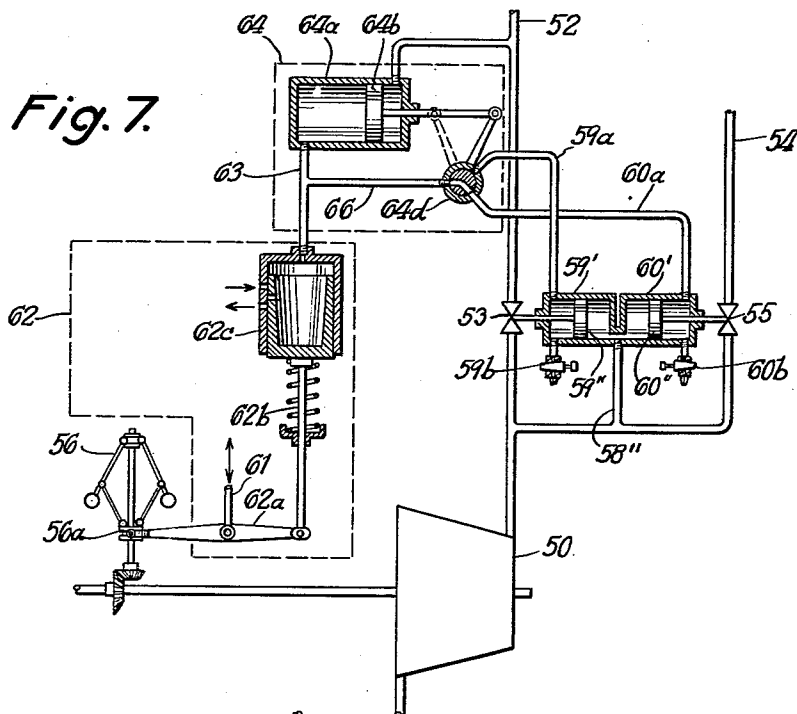


Fig. 5.

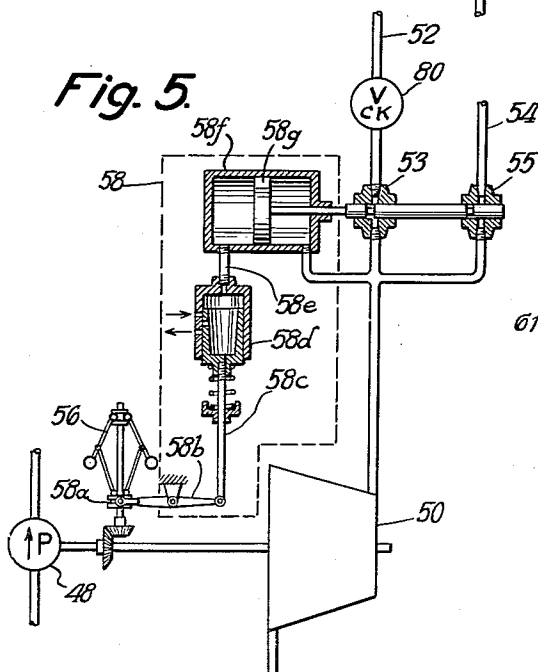
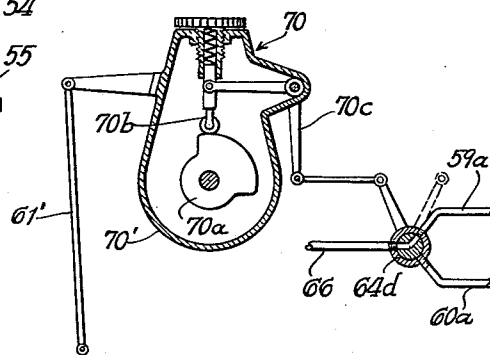


Fig. 8.



INVENTOR.
HANS VÖGLER.
BY *H. A. Mays*
ATTORNEY.

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3,083,536

APPARATUS FOR OPERATING A STEAM POWER PLANT INCLUDING A REHEATER AND TAPPED STEAM OPERATED STEAM CONSUMERS

Hans Vogler, Winterthur, Switzerland, assignor to Sulzer Freres, S.A., Winterthur, Switzerland, a corporation of Switzerland

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5 Claims. (Cl. 60—73)

The present invention relates to a steam power plant including a steam generator, a steam power engine having a high pressure part and a low pressure part, a reheater interposed between said two parts, and an additional steam consumer whereby steam is selectively tapped from a part of the steam power engine, and/or from the reheater to obtain steam for the additional consumer.

Steam power plants frequently comprise auxiliary machines, for example boiler feed pumps, which are driven by steam turbines. There are also other steam consumers, such as heaters, in addition to the main prime mover. It is conventional to obtain the steam for operating the auxiliary engines and/or for satisfying the steam demand of other steam consumers by tapping steam from the main engine of the plant. Since the pressure of the tapped steam varies according to the load on the main engine the pressure of the tapped steam is considerably lower when the load on the main engine is low than when this engine operates at full load. Of course, if the tapped steam operates feed pumps, less energy is required for these pumps when the plant operates at low load. However, if the load on the main engine drops below a certain minimum load, the pressure of the tapped steam is insufficient to answer the requirements of the feed pumps and steam must be tapped from a higher stage of the main engine.

It is an object of the present invention to provide in a steam power plant including a prime mover, such as a turbine, having at least two expansion stages and a reheater therebetween and at least one additional steam consumer apparatus whereby steam is available for the additional steam consumer at a desired pressure and a suitable temperature at all load conditions on the prime mover. According to the invention steam is selectively tapped from the prime mover and/or from the reheater at relative rates which depend on the load on the prime mover.

It is a further object of the invention to provide a control apparatus in a plan as specified in the paragraph next above whereby the selective steam tapping is automatically effected to efficiently satisfy the steam requirements of the additional steam consumer at variable load conditions on the prime mover and/or on a steam generator producing steam for the power plant.

The novel features which are considered characteristic of the invention are set forth with particularity in the appended claims. The invention itself, however, and additional objects and advantages thereof will best be understood from the following description of embodiments thereof when read in connection with the accompanying drawing wherein:

FIG. 1 is a diagram known as a Mollier diagram wherein the abscissae represent entropy of steam and the ordinates represent heat content of steam and into which the steam conditions in a plant according to the invention and operating at two different loads are plotted.

FIG. 2 is a diagrammatic illustration of a plant according to the invention.

FIG. 3 is a diagrammatic illustration of a modified portion of the plant shown in FIG. 2.

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FIG. 4 is a diagrammatic illustration of a modified plant according to the invention.

FIG. 5 is a diagrammatic part sectional illustration of a control apparatus for the plant shown in FIG. 4.

FIG. 6 is a diagrammatic illustration of a modification of a part of the plant shown in FIG. 4.

FIG. 7 is a diagrammatic part sectional illustration of a control apparatus for the plant shown in FIG. 6.

FIG. 8 is a diagrammatic illustration of a modified part of the apparatus shown in FIG. 7.

FIG. 1 of the drawing is a diagram wherein the abscissae represent entropy of steam and the ordinates represent heat content of steam. The dotted line shows the steam conditions in a plant operating at full load and having a steam engine with two expansion stages and a reheater therebetween. The steam leaving the second stage of the steam engine is condensed in a condenser. The solid line represents the steam conditions in the same plant when the plant operates at part load. The isobar ending at point A represents the steam conditions within the steam boiler. The steam enters the high pressure part of the steam engine at the condition A and expands in this high pressure stage to the condition B. The steam leaving the high pressure part of the steam engine is reheated in the reheater along the isobar B—C. The steam of the condition C enters the low pressure part of the steam engine wherein the steam is expanded to the pressure in the condenser. The steam enters the condenser at the condition D. It is assumed that steam is tapped from the low pressure part of the steam engine at the condition E. This steam may be used for operating an auxiliary turbine for driving a pump forming part of the steam power plant. The adiabatic pressure drop available for operating the auxiliary turbine is represented by the dotted line E—F. If the load on the main steam engine is reduced, the condition of the steam at the outlet of the boiler and at the inlet of the high pressure part of the main engine corresponds to point A'; the condition at the outlet of the high pressure part and at the inlet of the reheater is represented by point B'; the condition of the steam at the outlet of the reheater and at the inlet of the low pressure part is represented by point C'; the condition of the steam leaving the low pressure part and entering the condenser is represented by point D'. The temperature t_1 of the steam at point A' is the same as at point A. If steam is tapped during part load operation from the low pressure part at the condition E' and at the same tapping point as during full load operation, the available adiabatic pressure drop E'—F' is considerably smaller than the pressure drop E—F available from the tapped steam at full load operation. If the pressure drop available from the tapped steam at part load operation is insufficient for operating the auxiliary turbine, steam of higher pressure must be tapped from the low pressure part of the steam engine. If this is done, the temperature of the steam is considerably higher and may not be suitable for operating the auxiliary turbine or satisfying the demand of another steam consumer.

According to the invention, if the pressure drop available from steam tapped at a certain point of a steam engine is insufficient, tapping is not switched to a higher pressure point of the steam engine, but steam is tapped from the reheater whereby sufficient pressure drop can be obtained without raising the temperature of the steam entering the auxiliary turbine or consumer.

The condition of the steam tapped according to the invention from the reheater is designated by point G in FIG. 1. This point can be so chosen that the tapped steam has approximately the same temperature as the steam of the condition E'. The pressure drop available from the steam tapped from the reheater is represented

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by the line G—H. It has been found to be of considerable advantage if auxiliary turbines can be used which operate at relatively low inlet temperature which temperature does not substantially change when the load on the tapped turbine changes.

In the apparatus according to the invention a steam pipe for conducting steam from a suitable point of a reheater to an auxiliary machine or other steam consumer is added to the conventional pipe for conducting tapped steam from a main steam engine to the auxiliary steam consumer. Depending on the load on the main steam engine, steam is tapped from the low pressure stage of the main steam engine or from the reheater; the former is done when the steam engine operates at full load and the latter when the steam engine operates at partial load.

A control valve is interposed in at least one of the aforementioned pipes. This valve is preferably controlled according to a working condition of the steam plant, for example, the speed of an auxiliary turbine which is operated by the tapped steam.

In a modified arrangement according to the invention steam is tapped from a high pressure stage of the steam engine when the load on the engine is relatively small and is tapped from the reheater when the load on the main engine is great. It is also within the scope of the present invention to selectively tap steam from a high pressure stage of the main steam engine, from the reheater, and from a low pressure stage of the main steam engine, depending on the load on the latter.

FIG. 2 is a diagrammatic illustration of a steam power plant comprising a steam generator 1 from which live steam is conducted through a steam main 2 to a high pressure part 3 of a turbine. The steam exhausted from the high pressure part is conducted through a pipe 4 to a reheater 5 and therefrom to a low pressure part 6 of the turbine. The reheater 5 includes an intermediate collector 7 from which steam may be conducted through a pipe 10 to an auxiliary turbine 8 which drives an electric generator 9, a valve 11 being interposed in the pipe 10. This valve is by-passed by a pipe 12 in which an orifice plate 13 is interposed. Steam may be tapped from the low pressure part 6 of the main turbine and conducted through a pipe 14 containing check valves 15 and 16 to the auxiliary turbine 8. A pipe 17 is connected to the pipe 14 between the check valves 15 and 16 for conducting tapped steam to an additional steam consumer, for example, a feedwater heater 18. The pressure of the steam entering the turbine 8 is measured by a conventional device 19.

In order to provide the auxiliary turbine 8 with suitable steam also during periods of low load operation of the turbines 3, 6, the following control system is provided:

At normal load of the main turbine 3, 6 steam is tapped from the low pressure part 6 and supplied to the turbine 8 through the pipe 14. The device 19 continuously measures the pressure of the steam entering the turbine 8. The steam pressure in the pipe 14 becomes smaller when the load on the turbine 3, 6 is reduced and the pressure-responsive device 19 actuates by means of a conventional control apparatus the valve 11 for conducting steam from the reheater 5 to the turbine 8. A certain amount of steam, depending on the size of the orifice in the plate 13, flows through the pipes 10 and 12 also when the valve 11 is closed so that the pipe 10 is always heated and condensing of steam therein at a sudden opening of the valve 11 is prevented.

FIG. 3 diagrammatically illustrates a modified control system of the plant shown in FIG. 2. In this case a control valve 20 is provided also in the pipe 14. The controlled variable in the control circuit is measured by a device 21 which is responsive to the speed of the turbine 8. The device 21 actuates the valve 20 by conventional control apparatus, which are not shown in detail, opening the valve 20 upon a decrease of the speed of the turbine

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8 below the desired speed and closing the valve 20 upon an increase of the speed of the turbine 8 above the desired speed. When the valve 20 is fully open and the speed measured by the device 21 is still below the desired speed the valve 11 is opened, admitting steam from the reheater 5, opening of the valve 11 continuing until the turbine 8 operates at the desired speed. When the valve 11 is opened the valve 20 is closed and provision of a check valve in the pipe 14 is not absolutely necessary. When the load on the turbine 3, 6 is increased to normal or full load whereby the steam generator 1 is also operated at full output the pressure of the steam supplied through pipe 10 to the turbine 8 rises, causing an increase of the speed of the turbine and closing of the valve 11 and simultaneously opening of the valve 20 so that steam is tapped from the low pressure part 6 of the main turbine for operating the turbine 8.

In the plants schematically illustrated in FIGS. 4 to 6 steam generated in a boiler 30 having a superheater 31 is conducted through a steam main 32 to a high pressure part 33 of a main turbine. The exhaust of the part 33 is conducted through a pipe 34 into a low pressure part 36 of the main turbine, a reheater 35 being interposed in the pipe 34. Steam is tapped from the turbine part 36 through a pipe 37 and conducted to a feedwater preheater 38. Steam is also tapped from the turbine 36 through a pipe 39 and conducted to a steam consumer 40. A pipe 41 conducts steam tapped from the low pressure turbine 36 to a feedwater preheater 42. The exhaust steam of the turbine 36 is conducted through a pipe 43 to a condenser 44. The condensate flows through a pipe 45 to a pump 46 which pumps feedwater through the preheater 42 into a feedwater tank 47 which supplies feedwater through a pipe 49 to a feed pump 48 which pumps the feedwater through the preheater 38 into the boiler 30. The output of the boiler 30 is controlled by conventional means, not shown, to correspond to the steam consumption of the turbines 33 and 36, or of the steam consumers which receive steam from these turbines. The feed pump 48 is driven by an auxiliary turbine 50 which receives steam from a pipe 52 supplied by steam tapped from an intermediate collector 51 of the reheater 35, or steam which is tapped from the high pressure turbine 33 through a pipe 54. A control valve 53 is interposed in the pipe 52 and a control valve 55 is interposed in the pipe 54. The valves 53 and 55 are controlled by a device 58 which is actuated in response to the steam admission pressure of the turbine 50 and in response to the speed of the turbine 50 which is measured by a speed-responsive device 56. At normal or full load output of the turbine 33, 36 the valve 53 is opened until the turbine 50 operates at the desired speed and the valve 55 is closed. If, upon a decrease of the load on the turbine 33, 36 or of the steam output of the boiler 30 the pressure of the steam received by the turbine 50 from the pipe 52 drops and the speed of the turbine 50 decreases in spite of full opening of the valve 53, the reduced steam admission pressure to the turbine 50 acting through the device 58 causes closing of the valve 53. At the same time the valve 55 is opened until the turbine 50 has the desired speed.

FIG. 5 is a more elaborate illustration of the control system which is diagrammatically illustrated in FIG. 4. The device 58 includes a cylinder 58f in which a piston 58g reciprocates. The space at the left side of the piston 58g receives or discharges a pressure fluid through a pipe 58e which is connected to a pilot valve 58d controlling flow of pressure fluid to or from the pipe 58e. The valve 58d is actuated in response to the positions of a sleeve 56a of the speed governor 56, the movements of the sleeve 56a being transmitted to the valve 58d by means of a lever 58b and a connecting rod 58c. The piston 58g is connected to the valves 53 and 55 for simultaneous operation thereof in response to the position of the piston 58g.

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The device operates as follows:

When the main turbine 33, 36 is operated at normal load steam for operating the auxiliary turbine 50 is tapped from the reheater 35 through a pipe 52 in which the valve 53 is interposed. A check valve 80 is provided in the pipe 52 between the reheater 35 and the valve 53. The valves 53 and 55 are actuated in response to the speed governor 56. If the speed of the pump 48 drops, the connecting rod 58c moves in upward direction and operates the valve 58d to admit more pressure fluid into the space in the cylinder 58f at the left side of the piston 58g, tending to move the piston to the right against the pressure acting on the right side of the piston which is equal to the pressure of the steam admitted to the turbine 50 through the pipe 52. Reduction of the speed of the turbine 50 is due to a drop of the steam admission pressure of the turbine and the pressure at the left side of the piston 58g is greater than at the right side so that the piston moves to the right and opens the valve 53, admitting more steam to the turbine 50 and causing a rise of the steam admission pressure and of the speed of the turbine.

The valve 55 remains closed until the valve 53 is fully opened. If movement of the piston 58g to the right continues, the valve 53 is closed and the valve 55 is opened so that steam is supplied to the turbine 50 through the pipe 54 which receives steam from the high pressure turbine 33. This operation prevails when the main turbine operates at partial load whereby the pressure of the tapped steam is relatively low. The check valve 80 definitely prevents flow of steam tapped from the turbine 33 through the pipe 54 and the valve 55 into the reheater 35. When the load on the main turbine increases and the pressure in the pipe 54 rises, the increased pressure acts on the right side of the piston 58 and causes speeding up of the turbine 50 so that the pressure on the left side of the piston 58g drops and the piston 58g moves to the left, opening valve 53 and closing valve 55.

FIG. 6 is a diagrammatic illustration of a modified system for controlling the steam admission to the auxiliary turbine 50 operating the feed pump 48 of a plant as shown in FIG. 4. Numeral 61 designates a conduit for a control signal which corresponds, for example, to the rate of feedwater flow to or the rate of steam flow from the steam generator 30. This signal is compared in a conventional device 62 with a signal produced by the device 56 which is responsive to the speed of the turbine 50 and of the feed pump 48. The signal p_s produced in the device 62 corresponds to the desired speed of the feed pump and consequently to the desired pressure of the steam driving the turbine 50. The signal p_s is conducted through conduits 63 and 66 to devices 59 and 60 which compare the signal p_s with a signal corresponding to the actual pressure of the steam admitted to the turbine 50 which signal is produced in the device 58' which is responsive to the actual pressure of the steam operating the turbine 50. The devices 59 and 60 control the valves 53 and 55, respectively, to admit enough steam to the turbine 50 to produce the desired speed thereof, i.e. to provide the steam admission pressure corresponding to the signal p_s .

The signal p_s is compared in a conventional device 64 with a signal p_1 produced in a device 65 which is responsive to the pressure of the steam in the intermediate collector 51 of the reheater 35. The signal produced by the device 64 effects selective connection of the devices 59 and 60 to the conduit 66 to permit operation of the device 60 and the valve 55 as described in the paragraph next above as long as the signal p_s is greater than the signal p_1 , i.e., as long as the required steam admission pressure to the turbine 50 is greater than the pressure in the reheater collector 51. If the pressure in the reheater becomes greater than the desired turbine admission pressure, i.e. if p_s is smaller than p_1 , the device 60 is blocked and the valve 55 is closed and the device 59

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is permitted to operate for providing the desired turbine admission pressure by controlling the valve 53.

With the aforescribed control system the auxiliary turbine 50 is automatically operated by steam tapped from the reheater when the load on the main turbine 33, 36 is high and is operated by steam tapped from the high pressure stage 33 when the load on the turbine is low and vice versa.

The control system shown in FIG. 6 is not only applicable to the plant shown in FIG. 4 but can also be applied to the plant shown in FIGURES 2 and 3 whereby the device 65 would be connected to the pipe 14, and the signal corresponding to the desired speed of the turbine 8 would be compared with the signal corresponding to the pressure of the steam tapped from the turbine 6 and the resulting signal would be used for switching control of the valve 20 to control of valve 11 upon a decrease of the steam pressure in the pipe 14 below the desired pressure for operating the turbine 8.

FIG. 7 diagrammatically illustrates a mechanical apparatus for implementing the system shown in FIG. 6. As in the apparatus shown in FIG. 5 the sleeve 56a of the governor 56 actuates through a lever 62a and a connecting rod 62b a valve 62c which controls flow of a pressure fluid to or from the conduit 66 and to and from a control cylinder 64a. A piston 64b is axially movable in the cylinder 64a. On the left side of the piston acts the pressure defined by the valve 62c and on the right side of the piston acts the pressure prevailing in the pipe 52. A three-way valve 64d is connected to the piston 64b for operation thereby. The valve 64d controls flow of signal fluid from the conduit 66 either through a conduit 59a to the left side of a piston 59' in a cylinder 59' or through a conduit 60a to the right side of a piston 60' in a cylinder 60'. The space at the right side of the piston 59' and the space at the left side of the piston 60' are connected by a pipe 58'' to the steam admission pipe of the turbine 50. The piston 59' actuates the valve 53 and the piston 60' actuates the valve 55. Fluid relieve cocks 59b and 60b are connected to the space at the left side of the piston 59' and to the space at the right side of the piston 60', respectively.

In contradistinction to the apparatus shown in FIG. 5 the fulcrum of the lever 62a is not stationary, but is displaced in response to a desired set point for the control system which may correspond, for example, to the rate of feedwater supplied to the steam generator, or to the rate of output of the generator.

The device operates as follows:

The valve 62c is actuated in dependence on the speed of the turbine 50 required for effecting the desired rate of feedwater supply to or output of the steam generator so that the fluid pressure p_s at the left side of the piston 64b corresponds to the desired operation of the turbine 50. If the pressure p_s is greater than the steam pressure p_1 in the pipe 52 which receives steam from the reheater 35, the piston 64b moves to the right, placing the valve 64d in the position shown in FIG. 7 for connecting the conduit 66 to the conduit 60a and to the space at the right side of the piston 60' in the cylinder 60'. Depending on the difference between the pressure p_s and the steam admission pressure p_1 , the piston in the cylinder 60' is moved until the valve 55 is in the position to admit sufficient steam through the conduit 54 to the turbine to produce the desired turbine speed. The valve 53 is closed because the pressure fluid is relieved by the cock 59b from the left side of the piston 59'. If the pressure p_s drops below the pressure p_1 , the piston 64b moves to the left so that the valve 64d connects the conduit 66 to the conduit 59a and to the space at the left side of the piston in the cylinder 59', causing operation of the valve 53 which admits steam from the reheater to the turbine 50. The device 60' is inoperative at this time and the pressure is relieved from the right side of the piston

60" through the cock 60b and the piston 60" moves to the position for closing the valve 55.

FIGS. 2 to 7 illustrate examples of the invention whereby steam is selectively tapped from a main turbine or a reheater according to the load on the turbine. FIG. 8 illustrates the adaptation of the system shown in FIGS. 4 to 7 to the control of the selective tapping of the steam from the main turbine or from the reheater by a device controlling the output of the steam generator, for example, as disclosed in Patent No. 2,962,865. FIG. 8 merely illustrates a detail of the systems shown in FIG. 7 which must be modified in order to make the control directly responsive to a steam generator load control device. The latter is diagrammatically shown in FIG. 8 and designated by numeral 70 and controls in the conventional manner, for example the rate of fuel supply, of combustion air supply, and of feedwater supply, if desired. The device 70 includes a cam 70a acting on a roller 70b connected to a lever 70c which actuates the valve 64d shown in FIG. 7. If the valve 64d is in the position shown in FIG. 8, the conduit 66 is connected to the conduit 59a when the control device for the steam generator is set for full load operation so that the auxiliary turbine 50 receives steam from the reheater through the pipe 52. For operating the steam generator at partial output the cam 70a is rotated relative to a base 70' to effect clockwise movement of the valve 64d for connecting the conduit 66 to the conduit 60a so that the turbine 50 is supplied with steam from the high pressure turbine 33 through the pipe 54 and the valve 55. The base 70' of the load control device 70 may be adapted to be swung on the axis of the cam 70a, without changing the relative position of the cam and of the base, by means of a rod 61' for placing the cam in a position corresponding to a desired set point.

I claim:

1. A steam plant comprising a steam generator, a steam engine having a high pressure stage connected to said generator for receiving steam therefrom, a reheater connected to said high pressure stage for receiving the exhaust steam therefrom, said steam engine having a low pressure stage connected to said reheater for receiving reheated steam therefrom, a steam consumer using up steam energy, a first steam pipe connected to said consumer and to one of said stages for directly conducting steam tapped therefrom to said steam consumer for supplying steam energy thereto, a second steam pipe connected to said consumer and to said reheater for tapping steam therefrom and conducting the steam tapped from said reheater to said consumer for supplying steam energy thereto, and valve means interposed in each of said pipes for controlling the relative flow of steam through said pipes from one of said stages and from said reheater to said consumer.

2. A steam plant as defined in claim 1 wherein said valve means in one of said pipes in a check valve.

3. A steam plant comprising a steam generator, a steam engine having a high pressure stage connected to said generator for receiving steam therefrom, a reheater connected to said high pressure stage for receiving the exhaust steam therefrom, said steam engine having a low pressure stage connected to said reheater for receiving reheated steam therefrom, at least one steam consumer,

a first steam pipe connected to said consumer and to at least one of said stages for conducting steam tapped therefrom to said steam consumer, a second steam pipe connected to said consumer and to said reheater for conducting steam tapped from said reheater to said consumer, and flow control means interposed in said pipes for controlling the relative flow of steam through said pipes to said consumer.

4. A steam plant comprising a steam generator, a steam engine having a high pressure stage connected to said generator for receiving steam therefrom, a reheater connected to said high pressure stage for receiving the exhaust steam therefrom, said steam engine having a low pressure stage connected to said reheater for receiving reheated steam therefrom, a steam consumer, a first steam pipe connected to said consumer and to one of said stages for conducting steam tapped therefrom to said steam consumer, a second steam pipe connected to said consumer and to said reheater for conducting steam tapped from said reheater to said consumer, valve means interposed in said pipes for controlling the flow of steam through said pipes to said consumer, steam pressure responsive means connected to one of said steam pipes downstream of the valve means therein and responding to the pressure of the steam entering the consumer, and actuating means connected to at least one of said valve means and connected to said pressure responsive means for actuating said valve means to increase steam admission to said consumer when said steam pressure drops below a predetermined pressure and to decrease steam flow to said consumer when said steam pressure exceeds a predetermined pressure.

5. A steam plant comprising a steam generator, a steam engine having a high pressure stage connected to said generator for receiving steam therefrom, a reheater connected to said high pressure stage for receiving the exhaust steam therefrom, said steam engine having a low pressure stage connected to said reheater for receiving reheated steam therefrom, an auxiliary steam engine, a first steam pipe connected to said auxiliary steam engine and to one of said stages for conducting steam tapped therefrom to said auxiliary steam engine, a second steam pipe connected to said auxiliary steam engine and to said reheater for conducting steam tapped from said reheater to said auxiliary steam engine, valve means interposed in said pipes for controlling the flow of steam through said pipes to said auxiliary steam engine, engine speed responsive means connected to said auxiliary steam engine, and actuating means connected to at least one of said valve means and to said speed responsive means for actuating said valve means to increase steam flow to said auxiliary engine when the engine speed drops below a predetermined speed and to decrease steam flow to said auxiliary engine upon an increase of the engine speed above a predetermined speed.

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