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2,902,831

GOVERNING SYSTEM FOR REHEAT STEAM TURBINE POWERPLANT

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This invention relates to steam turbine powerplants, particularly to very large capacity compound turbines operating with steam at an initial pressure above the "critical pressure," meaning at least 3206 p.s.i.a., and is particularly applicable to such powerplants having two heaters for reheating the steam after partial expansion in certain of the turbine sections.

The present invention is a further improvement of the reheat turbine governing system of U.S. Patent 2,811,837, issued November 5, 1957 in the name of M. A. Eggenberger, and assigned to the same assignee as the present application. As noted in considerable detail in that patent, a problem arises from the fact that super-critical pressure steam generators of the forced circulation or "once-through" type must be provided with means for recirculating steam during the starting cycle, without passing it through the turbines, until the steam generating cycle reaches appropriate temperature and pressure conditions. This is accomplished by providing variously arranged valves for bypassing the steam to the condenser and back to the steam generator without traversing any of the turbines. Such steam generators require a minimum flow rate of about 30% of the maximum flow rate and approximately 30% of rated pressures in the reheaters in order to bring the steam supply temperature up to proper values for starting the turbine; and, upon sudden decrease in load, the flow rate must be kept at least at a value of 30% of the maximum flow rate if damage to the boiler is to be avoided, since such a minimum flow rate is necessary in order to prevent overheating of the various tubes in the steam generator.

With a steam generator of the type described, it is of the utmost importance to exercise accurate control of the steam supply to the respective turbine sections during the starting cycle; and proper synchronization of the valve actuators is found to be difficult where the various valves required are widely separated. Furthermore, it is important that the steam supplied initially during the starting cycle be accurately metered to the respective turbine sections, in sufficient quantities as to provide the power required to bring the turbine rotor up to rated speed, and also to remove the heat generated by turbulence due to the fact that normal "design flow conditions" are not produced by the low turbine flow and 30% of rated reheat pressures. Without such "ventilation," the friction heat resulting from this turbulence would result in overheating of certain of the high pressure turbine sections.

Accordingly, an object of the present invention is to provide improved valve gear for a double reheat compound turbine with special means for admitting high pressure steam to produce no-load power, and ventilate the turbine sections, during the starting cycle.

A further object is to provide reheat turbine valve gear of the type described actuated by mechanism permitting very accurate operation in proper sequence of the starting valves, in order to appropriately meter high pressure steam to the respective turbine sections.

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Another object is to provide steam turbine governing mechanism of the type described employing valves and pipes of minimum size.

Still another object is to provide starting valve mechanism for a compound reheat turbine using high pressure steam, so as to use a minimum quantity of steam for performing the starting and ventilating functions.

Other objects and advantages will become apparent from the following description taken in connection with the accompanying drawing, in which the single figure is a diagrammatic representation of a multi-section double reheat steam turbine powerplant supplied with supercritical pressure steam from a boiler of the forced circulation type and having special starting valve means arranged in accordance with the invention.

Generally stated, the invention is practiced by providing a double reheat compound steam turbine with separate starting valves for admitting carefully controlled quantities of steam from the high pressure steam supply directly to each of the high pressure and intermediate pressure turbine sections, so as to bring the turbine rotor up to normal rated speed while providing sufficient steam flow to remove the heat generated by turbulence in the turbines due to the fact that the flow passages are not operating at full design conditions, with resulting inefficiency which shows up as friction heat.

Referring now to the drawing, the invention is illustrated as applied to a compound double reheat steam turbine powerplant having a very high pressure or "super pressure" turbine section 3, a high pressure turbine section 4, two intermediate pressure turbine sections 5, 6, and two low pressure sections 7, 8. The turbine elements 3, 5, 7 comprise the first turbine unit 1; and elements 4, 6, 8 comprise the second turbine unit 2. As will be appreciated by those acquainted with such powerplants, the turbine units 1 and 2 may have mechanically independent rotors, connected to separate generators, not shown. The drawing shows in considerable detail the piping and valve mechanism for connecting these turbine sections with the steam generator, and includes a complex bypass arrangement for starting the steam generator while bypassing steam through the reheaters and to the condenser without going through the turbines. The full mechanical details of this bypassing arrangement are not necessary to an understanding of the present invention, but the showing in the drawing taken with the general outline of the operation below will be helpful in understanding the advantages of the starting valve mechanism to which this invention particularly relates.

This starting valve arrangement comprises the pilot valve member 10 of the main control valve 9, and the special starting valves 11 and 12. As will be seen more particularly in the description of the operation below, these valves must be operated in a precise sequence relative to the high pressure intercept valve 13, and the two intermediate pressure intercept valves 14 and 15. To this end, the valves 9, 11, 14 and 12 may be actuated by a number of cams disposed on a common cam-shaft 16 carrying a pinion 17 adapted to be positioned by a rack 18 carried on an actuating rod 19 pivoted to the main governor lever 20. The intercept valves 13, 15 are likewise actuated by cams 21, 22 carried on a common cam-shaft 23 actuated by pinion 24 and rack 25 carried on the rod 26 pivoted to the left-hand end of the pre-emergency governor lever 27. The main governor 28 is at all times free to act, upon increase in speed above the value for which it is set to lower the link 30, and thus rotate the shaft 31 so as to pull downwardly on the lost-motion connecting link 32 and rotate lever 27 counterclockwise about the speed setting screw 33 so as to actuate cam shaft 23 to move the valves 13, 15 toward the closed condition. Likewise, the pre-emergency governor 34 is always free

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to pull down on lever 27, irrespective of the condition of governor 28, to close the intercept valves 13, 15 if the speed for which governor 34 is set is exceeded.

In normal operation, the main governor 28 positions the lever 20 so as to actuate the cam-shaft 16 to position the main control valve 37 so as to hold speed or load at the value determined by the setting of the synchronizing device 29. If it is desired to establish a maximum load beyond which the governing mechanism cannot admit more steam to the turbine, the adjustable load limit abutment 35 may be positioned toward the right-hand end of lever 20 so that the lever cannot move upwardly more than an amount corresponding to this preselected maximum load. In starting the powerplant, this load limit abutment 35 performs an additional function noted hereinafter.

It will be apparent from the drawing that the actuating rod 36 of the main control valve gear 9 acts first to raise the pilot valve disk 10 so as to admit a small quantity of steam through the port provided in the main valve disk member 37, in a manner which will be apparent to those acquainted with turbine valves. After moving a preselected distance, the valve disk 10 engages the top of the main valve disk 37 and causes it to rise from its seat.

The starting valve 11 is connected to supply appropriate quantities of steam to the inlet end of the intermediate pressure turbine 5 by way of conduit 38 and a flow-limiting orifice 39, also by way of conduit 38 to the inlet end of the intermediate pressure turbine 6, past a flow-limiting orifice 40.

The starting valve 12 is connected to supply carefully metered quantities of steam through conduit 41, past a flow-limiting orifice 78, to the inlet end of the high pressure turbine section 4.

As will be appreciated by those acquainted with compound reheat type turbine powerplants, the "intercept valve" 14 is an emergency stop valve arranged to shut off the supply of motive fluid to the intermediate pressure turbine 5 from the low pressure reheater 42. Similarly, the high pressure intercept valve 13 serves to shut off the flow of steam from the high pressure reheater 43 to the inlet end of the high pressure turbine section 4. Finally, the intercept valve 15 serves to stop the flow of steam from the low pressure reheater 42 to the inlet end of the intermediate pressure turbine 6.

Numerous other details of the system shown will be readily apparent from the drawing to those acquainted with compound steam turbine powerplants. The steam generator comprises the boiler 44 having a conventional boiler feed pump 45 and feedwater heater system 46, the details of which are not important here. From the boiler, the steam passes to a superheater section 47 and after passing through certain of the turbine sections it is returned to the high pressure reheater 43 and, after further expansion, to the low pressure reheater 42. The main stop valve 48, disposed immediately upstream from the main control valve gear 9, is arranged to be closed quickly by an overspeed governor 49 in the event turbine speed rises to a preselected maximum value. The reheat stop valves 72, 73 and 74 are also arranged to be closed quickly by suitable similar overspeed governors, not shown. The speed governor 34 is known as a "pre-emergency governor," and acts to begin to close the intercept valves 13, 15 before the turbine rotor reaches the speed at which the main stop valve 48 would be tripped.

Other details of the piping and the special bypass valves required in the operation of the system will be apparent from the outline of the integrated operation given below. In describing the operation of the complete plant, it is to be noted that three principal operating conditions are represented by different flow path arrows, as indicated by the legend on the drawing. Solid arrows represent steam flow in normal operation. Dash-dot arrows represent the flow during the starting cycle of the steam generator, before motive fluid is admitted to the turbines. Dotted arrows

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illustrate the starting cycle of the turbines. Dash lines indicate condition-sensing signals; and a pressure signal is represented by an encircled P, and a temperature signal by an encircled T.

The complete operating cycle of the plant is as follows.

Assume first that the steam generator and turbine are cold. The boiler feed pump, driven by a suitable electric motor (not shown) operates to circulate cold water through the boiler 44, superheater 47, then through the bypass valve 50, conduit 51, water separator 52, thence through conduit 53 direct to the condenser hot-well 54. When approximately 30% of rated flow is thus established, the boiler is fired and the temperature of the water begins to rise. The boiler feed pump is so operated that the water pressure rises to the full rated pressure, which may for instance be 3500 pounds per square inch, gage. Thus the water remains in the liquid phase with no evaporation taking place. The "super-pressure bypass valve" 50 is so controlled by the temperature and pressure sensing connections shown in the drawing that this 3500 pounds per square inch pressure is maintained in the superheater and boiler. However, as the water temperature rises, it eventually acquires enough thermal energy that a certain amount of it flashes into steam as it passes through the valve 50. The steam is separated from that portion which remains liquid in the separator 52. As before, the water is returned by conduit 53 to the condenser hot-well 54. The vapor passes from the upper portion of water separator 52 by way of conduit 55 through conduit 56, the high pressure reheater 43 thence through conduit 57 to the high pressure bypass valve 58, and through conduit 59 to the low pressure reheater 42, and by way of conduit 60 and low pressure bypass valve 61 to the condenser 62.

As the heat input to the boiler 44 increases, the temperature of the fluid rises to the point where all the fluid passing through the super-pressure bypass valve 50 is steam, which temperature may be on the order of 875° F. This is a sufficiently high temperature that it would damage the piping and condenser tubes. Therefore, water is supplied to the desuperheating water spray chambers 63, 64, and 65. These desuperheaters are of course provided with automatic temperature control devices (not shown) so the water injected maintains the steam exit temperature at safe values.

During this process, the high pressure bypass valve 58 and the low pressure bypass valve 61 are adjusted manually so as to gradually raise the pressures maintained in the high pressure reheater 43 and the low pressure reheater 42 to values about 30% of the rated values; that is, on the order of 350 p.s.i.g. and 100 p.s.i.g., respectively.

Thus the steam generating system has arrived at operating conditions at which it is appropriate to begin admitting steam to the turbines. In order to warm up the "super-pressure turbine" 3 and the high pressure turbine 4 (in order to limit the "thermal shock" which occurs when steam at the temperature now produced by the steam generator is suddenly admitted to the cold turbines), a small amount of warming steam is admitted by manually opening the valve 66. This admits steam directly from the high pressure reheater 43 to the discharge end of turbine 3. Similarly, valve 67 is opened to admit steam from conduit 81, which is shown connected to conduit 60. This admits steam from the low pressure reheater 42 through conduits 60, 81, 69 to the discharge end of the high pressure turbine 4. This steam brings the turbine casings 3 and 4 up to about 30% of rated pressure and supplies enough heat to bring these turbines to temperatures which may for instance be on the order of 420° F. for the super-pressure turbine 3 and 330° F. for the high pressure turbine 4. Suitable check valves are provided as shown in the drawing to prevent reverse flow through the warming valves 66, 67. Once the super-pressure turbine 3 and the high pressure turbine 4 are

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brought up to pressure and appropriately warmed, the valves 66, 67 are manually closed.

The boiler stop valve 70 is now opened manually, admitting steam to the conduit 71, which contains the main stop valve 48, located immediately upstream from the main control valve gear 9. Now it is necessary to manually open the main stop valve 48, the high pressure reheater stop valve 72, and the low pressure reheater stop valves 73 and 74.

The adjustable load limit device 35 also serves as a manual starting device, and is now backed away from the right-hand end of lever 20, which follows the load limit abutment upwardly, by reason of the bias of the spring in governor 28. This causes rack 18 to rotate the cam shaft 16 so that cams 75, 76, and 77 begin to open the pilot valve 10 in the main control valve 9 and the other two starting valves 11, 12, respectively. This admits steam at an initial pressure of 3500 p.s.i.g. into the super-pressure turbine section 3, the intermediate pressure turbine section 5, and the high pressure turbine section 4. Steam is also admitted through conduit 38 to the intermediate pressure turbine section 6. This flow is limited by suitable orifices 39, 40 and 78 so as to maintain a high pressure in these conduits, permitting them to be of smaller physical size than would be required if the steam were permitted to expand freely therein.

The contours of the cams 75, 79, 77, are so selected as to cause the three starting valves 10, 11, 12 to admit quantities of steam to the turbines 3, 5, 4, and 6 adequate to provide the "no-load power" to bring the turbine up to normal rated speed, which may for instance be 3600 r.p.m. The quantity of steam thus provided is also so selected as to remove the heat generated by turbulence in the respective turbine sections, as noted above.

As the speed of the turbine rotor reaches the range in which the governor 28 becomes effective, the synchronizing device 29 is actuated to control the speed and appropriately bring it up to the desired rated speed. Once rated speed is established, the generator driven by the turbine (not shown) can be connected to the electrical network to which it delivers power. The governor 28 will now maintain stationary in space the pivot point 80, and the synchronizing device 29 can be actuated to further open the starting valves 10, 11, 12. Any tendency of the turbine rotor to overspeed is prevented by the fact that the generator is delivering power to a 60-cycle A.C. network to which other constant speed turbines are also delivering power, and the electrical characteristics of the system keep the generator approximately at 3600 R.P.M. irrespective of additional opening of the starting valves.

This action continues until the cam-shaft 16 brings the starting valves 10, 11, 12 to their fully open condition. At this point, cam 76 begins to open the intermediate pressure intercept valve 14, cam 21 begins to open the high pressure intercept valve 13; and cam 22 starts to open the intermediate pressure intercept valve 15. This causes steam to be admitted from the high pressure reheater 43 through conduit 57 to valve 13 and to the inlet of the high pressure turbine section 4. Also, steam is admitted from the low pressure reheater 42 through conduit 60 and conduit 81 to the intermediate pressure intercept valve 15 and to the inlet of intermediate pressure turbine 6. Steam is also admitted from the low pressure reheater 42 through conduit 60, conduit 63 to the intermediate pressure intercept valve 14, and to the inlet of intermediate pressure turbine 5. At the same time as the intercept valves 14, 13, and 15 begin to open, the valve actuating rod 36 begins to lift the main governing valve disk 37.

Speed synchronization is necessary in order that the two units be locked in step electrically prior to connecting to the electrical network. Synchronization is also desirable in order that the proper operating sequence and timing, as accomplished by the valve cams, will produce

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optimum temperature and pressure conditions. In order to synchronize units 1 and 2, the generator rotors must be turning within approximately 5% of rated speed or any predetermined fraction of rated speed in order to prevent serious rotational acceleration or overheating of the fields at the moment the field is applied. Speed synchronization between the units shown is accomplished by means of speed setting screw 33. Since the super-pressure steam being supplied by starting valve 12 to the high pressure unit 4 would normally be inadequate to bring unit 2 to within approximately 5% of its rated speed where the shaft-driven exciters could safely provide the synchronizing excitation necessary to lock the rotors electrically, additional steam must be supplied to unit 2. Upon unit 1 reaching rated speed, therefore, at no load, additional steam may be supplied to unit 2 to bring it within the synchronizing range by manipulating speed setting synchronizing screw 33 so as to cause high pressure intercept valve 13 and intermediate pressure intercept valve 15 to open and overcome this deficiency. As soon as synchronization has been accomplished, speed setting screw 33 may be returned to its previous position and the starting sequence again is in control of the governing system with its associated cams.

Synchronization may also be accomplished during the starting cycle at less than rated speed, for example at 50% rated speed, which is approximately the minimum speed at which the shaft-driven exciters will become effective to supply proper excitation to the generator field. The operation during synchronizing is the same, it only being necessary first to adjust synchronizing device 29 to operate unit 1 at 50% speed and then to manipulate speed setting synchronizing screw 33 so as to bring unit 2 within approximately 5% of half of its rated speed. When this is done, the shaft-driven exciters are providing sufficient voltage to allow units 1 and 2 to be interconnected electrically and to allow the starting process to proceed with the generator rotors of units 1 and 2 turning in phase.

Further actuation of the synchronizing device 29 begins to close the starting valves 11 and 12. The shape of the respective cams are so designed that the intercept valves 14, 13, and 15 admit steam to the respective turbine sections at such rates as to provide the required power for synchronizing, and adequate flow of steam for ventilation to prevent overheating.

The turbine is now producing a significant power output and further actuation of the synchronizing device 29 increases this load. As the load increases, the starting valves 11, 12 progressively close, and the main valve 9 and intercept valves 13, 15, and 14 open. By the time the power output reaches approximately 30% of rated load, the intercept valves 14, 13, 15 are wide open and the starting valves 11, 12 are completely closed. This is the normal operating condition.

During this starting process, the super-pressure bypass valve 50 has been acting automatically to hold the discharge pressure from superheater 47 at the rated pressure of 3500 pounds per square inch absolute and to by-pass through conduit 51 that portion of the flow from the steam generator which cannot pass through the starting valves 11, 12, and 10. By the time 30% load is reached, the super-pressure bypass valve 50 is completely closed, and all the steam flow is going through the main control valve 9. Similarly, the high pressure bypass valve 58 and the low pressure bypass valve 61 have been progressively closing, and reach fully closed position at the 30% load condition. All the boiler flow is now passing through the main inlet valve 9 to turbine 3, and through intercept valves 14, 13 and 15 to the turbines 5, 4, and 6, respectively.

The plant is now in normal operation and the starting valves 11, 12 are inactive. The governor 28 now operates to position the main control valve 9 to determine the power output, the speed continuing to be held con-

stant by the electrical interconnection with the power network.

In the event the load on the turbine drops below the 30% condition, the operation is somewhat the inverse. That is, the cam-shafts 16, 23 begin to close the intercept valves 14, 13, 15, and the starting valves 11, 12 again begin to open so as to maintain the required ventilating flow through the respective turbine sections. The manner in which this is effected will be obvious from the above description of the starting process.

If the load decreases sufficiently, the intercept valves will be completely closed and all the boiler flow will again be flowing through the starting valves 10, 11, 12. Upon further decrease, the starting valves progressively close and an increasing quantity of steam is bypassed by automatic actuation of the valves 50, 61, and 58. When all the flow is traversing these bypasses, with the starting valves completely closed, the steam generator is in condition to be shut down.

Thus it will be seen that the starting valve mechanism to which the invention particularly relates affords accurately controlled and reliable means for metering carefully predetermined quantities of steam to the respective turbine sections so as to supply desired amounts of power during the starting cycle while maintaining flow rates adequate to provide the ventilation required to carry away the heat generated by fluid friction produced by the sub-standard flow conditions in the respective sections. It will be apparent from the above description of the structure that the starting valves may be physically grouped close together and actuated by common mechanism, capable of effecting very accurate synchronization of the operation of the respective valves. It should, however, be understood that the actuating mechanism shown in the drawing is purely diagrammatic, and many equivalent electrical, hydraulic, or pneumatic servo-mechanisms might be employed to actuate the respective valves in the sequence prescribed herein. By using high pressure steam taken directly from the main inlet conduit 32, the starting valves and their related conduits may be made comparatively small. This is advantageous because the compact arrangement of the valves makes it important that they all be as small as possible because of the physical limitations of the space available for the interconnecting piping around the valve chest. Also, the physical size of the valves themselves becomes an important factor when so many valves are closely grouped.

Numerous modifications and substitutions of equivalents will be apparent to those skilled in the art, and it is of course intended to comprehend in the following claims all such changes as fall within the true spirit and scope of the invention.

What we claim as new and desire to secure by Letters Patent in the United States is:

1. For use in a compound reheat steam turbine powerplant having means for generating steam at a high inlet temperature and pressure, a first turbine section connected to receive motive fluid at said high inlet conditions, at least one reheater connected to reheat the steam discharged from said first turbine section, at least one

lower pressure turbine section connected to receive motive fluid from the reheater, intercept valve means controlling the flow of steam from the reheater to the lower pressure turbine, and a condenser receiving spent motive fluid from the lowest pressure turbine, the combination of means including pressure regulating valve means for automatically bypassing fluid from the steam generating means to the condenser during the starting cycle, starting valve means connected to admit limited quantities of motive fluid from the steam generating means at said inlet temperature and pressure to the first turbine section in quantities sufficient to supply no-load power to bring the turbine rotor up to normal operating speed and to effect sufficient flow through the turbine to prevent overheating, second starting valve means connected to admit limited quantities of steam from the steam generating means at said inlet temperature and pressure to said lower pressure turbine section in quantities sufficient to generate no-load power and prevent overheating, and means connected to actuate said starting valve means and intercept valve means (1) to progressively open the starting valve means while the pressure regulating valve means regulates the steam bypassed to the condenser, with the intercept valve means remaining closed; and (2) to progressively close the starting valve means as the intercept valve means opens; and (3) to maintain the starting valves completely closed and the intercept valve completely open in normal operation, with the pressure regulating valve means bypassing no steam to the condenser.

2. For use in a compound reheat type steam turbine powerplant having means for generating steam at a high inlet temperature and pressure, a first turbine section connected to receive motive fluid at said high inlet conditions, at least one reheater for reheating the steam discharge from said first turbine section, at least one lower pressure turbine section connected to receive motive fluid from said reheater, and intercept valve means controlling the flow of steam from the reheater to the lower pressure turbine, the combination of first starting valve means connected to admit limited quantities of motive fluid from the steam generating means at said inlet temperature and pressure to the first turbine section in quantities sufficient to supply no-load power to bring the turbine rotor up to normal operating speed and to effect sufficient flow through the turbine to prevent overheating due to fluid friction, second starting valve means for admitting limited quantities of steam from the steam generating means at said inlet temperature and pressure to said lower pressure turbine section in quantities sufficient to generate no-load power and prevent overheating due to fluid friction, and means for actuating said starting valves to admit motive fluid from the steam generating means simultaneously to said first and second turbine sections, said actuating means being connected to progressively close the starting valves as the intercept valve means opens, the starting valves being completely closed when the intercept valve means is wide open.

No references cited.