POWER GENERATING UNITS

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Filed Sept. 16, 1965, Ser. No. 487,751
14 Claims. (Cl. 60—64)

ABSTRACT OF THE DISCLOSURE

A self-starting power generating unit which operates on a closed Rankine cycle. The unit includes a boiler with heating means and a turbine having nozzles that are fed with vapor generated by the boiler. The exhaust from the turbine is led to a condenser. The condensed liquid is returned to the boiler. The turbine includes bearings which are lubricated by the condenser condensate. At least one of the turbine nozzles is continuously supplied with vapor from the boiler during start-up and slow-down when the pressure is below the design value for driving the turbine at operating speed.

The present invention concerns power generating units operating on a closed Rankine cycle comprising a boiler for the evaporation of the motive fluid, a turbine fed with vapor from the boiler and driving a generator or any other load, a condenser for condensing the exhaust vapours from the turbine and means for recycling the condensed fluid to the boiler. Such power generating units will be referred to hereinafter as "power generating units of the kind specified."

In some power generating units of the kind specified, the motive fluid discharged from the liquid side of the condenser is returned to the boiler by pumping. Such units will be referred to hereinafter as "pump-fed power generating units of the kind specified."

In other power generating units of the kind specified, the condenser is mounted above the boiler at a sufficiently high level for the liquid motive fluid to return from the liquid side of the condenser to the boiler by gravity flow. Such units will be referred to hereinafter as "gravity-fed power generating units of the kind specified."

The invention is concerned with both pump-fed and gravity-fed power generating units of the kind specified.

It is quite generally the object of the present invention to provide power generating units of the kind specified that are "self-starting" meaning that they can be started by just turning on the heat and that they stop automatically, without damage, after the heat is turned off.

One basic requirement for a self-starting power generating unit of the kind specified is lubrication of all bearings during the start-up and slow-down periods with the liquid motive fluid itself. An arrangement by which the bearings in a power generating unit of the kind specified are lubricated with the liquid motive fluid will be referred to hereinafter as "auto-lubrication."

Auto-lubrication in power generating units has been proposed before. Thus, for example, according to U.S. patent specification No. 3,661,733 the bearings communicate by suitable passages directly with the discharge end of the feed pump of the unit. In this arrangement the lubrication is brought about by the pump which in turn is coupled to the turbine so that there is no provision for lubrication of the bearings during the start-up and slow-down periods when the pump is at rest. However, a preliminary lubrication of the bearings while the turbine is at rest is precisely what is required for self-starting power generating units of the kind specified.

According to another arrangement for auto-lubrication of the bearings in a power generating unit, described for example in U.S. patent specification No. 2,961,550, that portion of the motive fluid that is required for lubrication is branched off from the vapour space of the boiler and is conducted through a condenser into the oil in the bearings. Such an arrangement has however equally been found to be unsatisfactory both because tapping off the lubrication fluid from the vapour space leads to energy losses which can be prohibitive, especially for very small units of say below 1 kw. power output, and which can only be avoided by using a system of valves which reduce the reliability of the unit, complicates the design and prevents the unit from being self-starting, and also because the design is such that no or insufficient allowance is made for lubrication during the start-up and slow-down periods.

It is an object of the present invention to provide both pump-fed and gravity-fed power generating units of the kind specified adapted for self-starting by an auto-lubrication so designed that the bearings of any rotating members are lubricated automatically with the liquid motive fluid during the start-up, the operational and the slow-down periods. The term "start-up" is used herein to designate the period beginning with turning on of the boiler heat and ending when the nozzle supply of the turbine vapour is under design pressure. The term "slow-down" is used herein for the period beginning with the turning off of the boiler heat and ending with the complete standstill of the turbine.

In its most general aspect the invention provides a self-starting power generating unit of the kind specified wherein in the bearings to be lubricated communicate with a container for the liquid motive fluid and liquid motive fluid flows freely to the bearings when the boiler is heated.

Where the self-starting power generating unit according to the invention is of the pump-fed type said container for the liquid motive fluid may be the boiler itself or an auxiliary vessel communicating with the boiler and located upstream the boiler and downstream the pump. In this case the arrangement is such that the liquid motive fluid used for lubrication is tapped off the return line of the liquid motive fluid upstream the boiler and downstream the pump. Such a specific location of the tapping off point between the boiler and the pump ensures smooth and uninterrupted lubrication during all operational phases of the unit. Thus during the start-up when the generator and pump are all still at rest liquid motive fluid from the boiler is forced into the bearings by the pressure which gradually builds up in the boiler. During the following operational phase when the pump operates, feeding of lubricating fluid into the bearings is taken automatically by the pump without any interruption. Where in the course of the operation the pump is interrupted either intentionally or unintentionally lubrication of the bearings is again taken over by the boiler and continues uninterrupted in consequence of the pressure prevailing in the boiler. Likewise, during the slow-down period the lubrication fluid originates again from the boiler and is forced thereafter into the bearings by the residual pressure still prevailing in the boiler.

When the lubrication is of the hydrodynamic type, the design of a pump-fed power generating unit according to the invention is preferably such that the excess lubricating liquid discharged from the bearings is drained and combined with the motive fluid discharged from the condenser and is recycled together with the latter into the boiler.

In a preferred embodiment of a self-starting pump-fed power generating unit according to the invention applicable where the power consumption of the pump is only a fraction, of the order of 1—5%, of the power of the unit, the pump is operated by a low-power turbine wheel or fan which is driven by the vapourised motive fluid and which may be located either between the boiler and the main turbine or between the latter and the con-
In such an embodiment the effect of the power consumption of the pump on the power output is negligible. Such an arrangement is very advantageous from the point of view of construction and efficiency.

Where the self-starting power generating unit according to the invention is gravity-fed, said container for the liquid motive fluid is either the sump of the condenser or an auxiliary vessel located on the liquid side of the condenser. In this case the bearings that are to be lubricated are located in the return path of the liquid motive fluid from the liquid side of the condenser to the turbine and at least one of the nozzles of the turbine is designed for a continuous vapour supply during the start-up and slows down the pump when the vapour pressure is below the design pressure of the turbine.

Thus in the gravity-fed embodiments of the invention vapour from the boiler can pass through the turbine even when the latter is not operating and is then condensed by the condenser from where the liquid motive fluid is fed to the bearings.

It is also possible in accordance with the invention to combine pump-fed and gravity-fed features by having the main fluid circulation brought about by pumping but at the same time mounting the condenser above the turbine in which lubrication occurs by gravity flow.

The invention is illustrated by way of example only in the accompanying drawings in which

FIG. 1 is a diagrammatic illustration of an embodiment of a self-starting pump-fed power generating unit according to the invention wherein the pump is driven by the exhaust vapours;

FIG. 2 is a diagrammatic illustration of a further embodiment of a self-starting pump-fed power generating unit according to the invention wherein the pump is operated by the vapours emerging from the boiler;

FIG. 3 is a modification of the embodiment of FIG. 1 wherein the pump is magnetically coupled with a cooling fan of the condenser;

FIG. 4 is a further modification of the embodiment of FIG. 1 with magnetic coupling between the pumps for the motive fluid and for the coolant;

FIGS. 6, 7 and 8 illustrate various arrangements designed to shorten the slow-down period; and

FIGS. 9 to 13 illustrate various bearing designs.

The power generating unit according to the invention illustrated in FIG. 1 is of pump-fed type in which the pump is driven by the exhaust vapours. The unit comprises a boiler 42 heated by a burner 43 and linked by a neck 44 to the manifold 45 of a turbine generator 46. An exhaust flue 47 leads from the exhaust side of unit 46 into a water-cooled condenser 50 fitted with a tray 51 serving for collecting the condensed motive fluid. Tray 51 is fitted with a drain 52 and is linked through duct 63 and 64 to the bearings of the turbine generator 46.

The pump portion of condenser 50 merges into a vertical cylindrical pipe 53 fitted with bearings 54, 55 designed in the form of ribs so as to allow for the passage of the condensed motive fluid. Journalled in bearings 54 and 55 is a shaft 56 on whose upper edge is keyed a windmill-type turbine wheel 57 and on whose lower end is keyed the rotor 58 of a centrifugal pump 59. The latter is linked by means of a duct 60 to boiler 42.

As the lubrication is of the hydrodynamic type a drainpipe 61 is provided for draining the excess lubrication fluid discharged from the bearings into cylinder 53. A further drainpipe 62 leads from the flue 47 equally into pipe 53 and serves for draining any liquid motive fluid accumulating in flue 47.

When burner 43 is turned on the vapourised motive fluid developed in boiler 42 passes through the still resting turbine and is discharged into the condenser 50 where it is liquified and collects in tray 51. Some of the liquid motive fluid discharges from tray 51 into the bearings while the rest is discharged through drainpipe 62, and if necessary by overflow, and flows into cylinder 53 to pump 58 back into the boiler 42.

The vapours discharged into the condenser impinge on the blades of turbine wheel 57 and thereby operate the latter. It is thus seen that during the start-up the bearings are lubricated and the pump operates, and also to the low pressures state obtaining during start-up and slow-down, when the main turbine is at a standstill, because of the low power requirement of the pump. When the pressure inside the boiler 42 has reached the design value, the turbine begins to rotate. When the heat is now turned off the operation of pump 59 and the lubrication of the bearings continue as long as any vapour emerges from the boiler and thereby lubrication of the bearings and circulation of the motive fluid is ensured also during the slow-down period.

It is seen that in this embodiment pump feeding and gravity flow are combined in that while the circulation of the main portion of the motive fluid is by pumping the lubrication of the bearings is by gravity flow.

The self-starting pump-fed power generating unit according to the invention illustrated in FIG. 2 is basically similar to the one according to FIG. 1 with the difference that the auxiliary turbine wheel for the operation of the pump is located in the path of the vapours from the boiler to the turbine. As shown boiler 65 is fitted with a burner 66 and comprises a vertical shaft 67 journalled in a bearing 68, and a stuffing box 70. On the upper end of shaft 67 is keyed a fan 71 and on the lower part of the shaft extending into a centrifugal pump 72 is keyed the pump rotor 73. The discharge end of pump 72 communicates through a short duct 74 with boiler 65.

The unit further comprises a turbine generator 75 and a water-cooled condenser 76 fitted with a trap 77 connected by means of a duct 78 with the bearings of turbine generator 75. The excess lubrication fluid is drained through a drainpipe 79 which merges into a duct 80 serving for returning the liquid motive fluid from the condenser and the bearings to the boiler.

During operation the vapour developing in boiler 65 is discharged through nozzles 69 and injected on fan 71 which is thus operated. Accordingly the pump is operated already during the start-up. The vapours discharged into the condenser are condensed there and collected in trap 77. From there part of the liquid motive fluid is led through duct 76 into the bearings of turbine 72, which is discharged from 75 by overflow, is returned through duct 78 to boiler 65. When eventually the design temperature is reached the turbine generator begins to operate.

It is thus seen that also in this unit lubrication and operation of the pump are ensured during the start-up period. Like in the embodiment of FIG. 1 lubrication and the operation of the pump continue even when the burner is turned off as long as there is any residual vapour in the unit and thus the operation of the pump and lubrication are also ensured during the slow-down, like in the embodiment of FIG. 1 lubrication is by gravity flow, while the main circulation of the motive fluid is by pumping.

The embodiment of FIG. 3 is a modification of the one according to FIG. 1 in that the water-cooled condenser of the latter is replaced by an air-cooled condenser. In FIG. 3 only the condenser and pump portions are illustrated while the remainder of the unit which is identical to that of FIG. 1, is not shown. As shown an exhaust flue 300 merges into a chamber 301 fitted with a neck 302 connected to an air-cooled condenser 303 comprising a plurality of fins 304. At its lower portion chamber 301 merges into a vertical cylindrical pipe 305 which is connected by a duct 306 to the liquid side of condenser 303. Pipe 305 houses a shaft 307 journalled in bearings 308.
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309 which are of similar design as bearings 54, 55 of FIG. 1. On the lower end of shaft 307 is keyed the rotor 310 of a centrifugal pump 311. On the upper portion of shaft 307, a key is overlaid by the auxiliary turbine wheel 312 of similar design and function as turbine wheel 57 of FIG. 1 and on the upper end of shaft 307 is keyed a horseshoe magnet 313.

In bearings mounted on a bracket 314 of the outer side of neck 302 is journalled a shaft 315 of a fan 316 and on the lower end of shaft 315 is keyed another horseshoe magnet 317. Accordingly turbine wheel 312 and fan 316 are magnetically coupled.

When during operation shaft 37 is rotated by the action of the exhaust vapours on windmill turbine wheel 312 fan 316 is equally rotated owing to the magnetic coupling, and thereby cooled 363 is cooled.

The embodiment shown in a fragmentary manner in FIG 4 is yet another modification of the embodiment of FIG. 1. In this embodiment the condenser is of the water-cooled type and as shown the rotor 320 of the motive fluid pump 321 is fitted with a horseshoe magnet 322. Likewise the rotor 323 of the water pump 324 serving for feeding water to the condenser, is fitted with a horseshoe magnet 325. The two magnets face each other on the two sides of a hermetic partition 326 and in this way the two pumps 321, 324 are coupled with each other. Thus when pump 321 is started by the exhaust vapours pump 324 operates as well and cooling water flows through the condenser. For the rest this embodiment is identical to the one of FIG. 1.

In a manner analogous to that illustrated in FIGS. 3 and 4 it is possible to utilize the auxiliary turbine or fan for operating one or other necessary equipment, either directly or through a generator.

The self-starting power generating unit according to the invention illustrated in FIG. 5 is of the gravity-fed type. It comprises a boiler 81 divided by the liquid level 82 into a liquid space 83 and a vapour space 84. Inside the liquid space 83 is located a heat storage element 85. Two ducts 86a and 86b connect the vapour space 84 of boiler 81 with two sets of nozzles of a turbine 87. The nozzles connected to duct 86b are controlled by a control valve 88 governed by a pressure-stat device (not illustrated). Turbine 87 fits its shaft 99 in common with an electric generator 90. The turbine 87 and generator 90 are enclosed within a casing 91 and shaft 89 is journalled in bearings 92 and 93 provided on internal brackets of the casing 91. Casing 91 is bent in a retort-like manner and its neck 94 serves as flue and leads to a condenser 95 whose collecting element 96 comprises an inlet pipe 97 fitted with a control valve 98, and an outlet pipe 99 for the coolant. The condenser 95 merges into a sump 100 for the collection of the condensed exhaust fluid. As can be seen clearly from the figure the condenser 95 is mounted above boiler 81 so that the condensed fluid can be recycled to the boiler by gravity.

From sump 100 a duct 101a leads into bearing 92 and a second duct 101b leads into bearing 93. The bottom portion of casing 91 is formed as a sump 103 and from the lowest point of that sump there leads a duct 104 into the liquid portion 83 of the boiler.

Below boiler 81 is located a burner 105 fitted with a fuel supply line 106 controlled by a main control valve 107 and an adjustment valve 108 which latter is in turn governed by a thermostat arrangement 109.

The nozzles connected to duct 86a are not governed by any control valve and are always open so as to supply air also during the start-up and slow-down phases, when control valve 88 is shut.

The above described power generating unit operates as follows:

Starting from the position of complete standstill valve 107 is opened and heat is supplied to boiler 81 by burner 105. Upon heating vapour develops in vapour space 84 and is conducted through pipe 86a, the associated nozzles and turbine 87 in neck 94 and is eventually condensed by condenser 95 and discharged into sump 100. During the start-up valve 88 remains shut and the turbine is inoperative because of small flow and low supply of energy (pressure below the design pressure). The liquid fluid that accumulates in sump 100 is conducted through ducts 100a and 100b into bearings 92 and 93 and the excessive liquid is drained into sump 103 from where it is discharged through duct 104 and conducted back to the liquid space 83 of boiler 81. The return of the liquid from sump 100 through the bearings 92 and 93, sump 103 and duct 104 into boiler 81 is entirely by gravity. In this manner bearings 92 and 93 are lubricated during the start-up phase.

As pressure builds up inside the boiler 81 control valve 88 is eventually opened by the associated pressure-stat device (not illustrated) and the nozzles connected to pipe 86b thus become operative. The unit begins to operate and produces electric energy. During the operational phase the fluid circulation inside the unit is exactly the same as in the pre-operational stage, while bearings 92 and 93 are continuously lubricated. During operation sump 100 serves as an accumulator for the liquid motive fluid so that the discharge of liquid through ducts 100a and 100b is at constant rate irrespective of any intentional or unintentional fluctuations in the nozzle supply to the turbine. When sump 100 is filled to capacity the excessive liquid is discharged by overflow 112 into sump 103.

In some cases, it may be preferable to omit valve 88. In such an event there will still be a start-up, both because of the inertia of the turbine and the time required for the necessary pressure to build up in boiler 81, and during this start-up the bearings will be lubricated as specified. Such a construction is particularly suitable for small turbines.

When it is desired to bring the unit to a standstill the heat is turned off whereupon the pressure inside the boiler 81 drops and the control valve 88 is shut. Because of the inertia the turbine 87 and generator 90 will continue to revolve for some time—slow-down—and during all that time lubrication is still required. The fluid for this purpose is provided by vapours from the still hot boiler in exactly the same manner as during the start-up. Since it may happen that the heat capacity of the boiler by itself is too low for a sufficient supply of vapour during the entire slow-down phase there is provided inside the liquid space 83 the heat storage element 85. This element is preferably of the phase-change type, i.e. a solid material enclosed within a sealed container and melting at a fairly well defined transition temperature which lies below the design operating temperature. When the boiler 81 cools down its temperature drops steadily until it reaches the transition temperature of the heat storage material. At this point the temperature remains constant until all the heat storage material has solidified after which the boiler continues to cool down to ambient temperature. During the phase-transition period of constant target temperature, considerable amounts of vapour are still produced whose pressure, however, is below the design pressure of the turbine. In this manner vapour for the supply of lubrication liquid during the slow-down is provided while at the same time the turbine is no longer operating.

In lieu or in addition to using a heat storage element 85 in order to prolong the vapour production for the entire slow-down phase, means can be provided for shortening the duration of the slow-down. Such means are illustrated in FIGS. 6, 7 and 8.

FIG. 6 is a fragmentary illustration of a unit of the kind illustrated in FIG. 5 showing only the boiler and condenser portions thereof. As shown boiler 111 is heated by a burner 112 whose fuel supply line 113 is controlled by a main valve 114 and an adjustment valve 115 governed by a thermostat arrangement 116.

The supply of coolant to condenser 117 is by way of a duct 118, fitted with control valves 119 and 120. Valve
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119 is governed by a thermostat 124 whereby the coolant flow is controlled during full rate performance of the unit so as to maintain the rate of condensation constant.

Valve 114 of the fuel supply line and valve 120 of the coolant supply are coupled by a transmission train comprising lever 121, rod 122 and lever 123 so that when the main fuel supply valve 114 is shut, valve 120 is shut with it. When valve 120 is shut the rate of coolant supply to condenser 117 is reduced with the result that the rate of condensation is equally reduced so that the exhaust pressure in the unit rises. This in turn causes a more rapid slow-down of the turbine once the heat supply to boiler 111 is interrupted.

The arrangement according to FIG. 7 is equally aimed at increasing the exhaust pressure in the unit and thereby to shorten the shut-down phase. In this embodiment this is achieved by a butterfly valve 145 linked to the main control valve 149 for the fuel supply by means of a transmission train comprising a lever 146, a rod 147 and a lever 148. When valve 149 is shut butterfly valve 145 is equally shut and consequently the exhaust pressure inside the unit is raised and has the same braking effect as in the embodiment represented in FIG. 6.

In the embodiment according to FIG. 8 there is connected across the terminals of generator 161 a resistor 162 fitted with a switch 163. Switch 163 is linked to the main valve 167 for the fuel supply through a transmission train comprising a lever 164, one rod 165 and a lever 166. When valve 167 is closed switch 163 is equally closed so that the resistor load 162 is connected to the generator with the result that the load on the generator is increased and the aggregate of turbine and generator comes to a standstill faster than would otherwise be the case.

It should be noted that in the pump-fed embodiment of this invention described with reference to FIGS. 1 to 4 it may also be desirable to prolong the vapour formation during the slow-down and/or to shorten the slow-down period, and this may be achieved in a similar manner as described above with reference to FIGS. 5 to 8.

In FIGS. 9 to 13 various embodiments of bearings for the rotors of units according to the invention are illustrated.

In the embodiment of FIG. 9 the turbine 170 and generator 171 are keyed on a common shaft 172 journaled in bearings 173, 174 located on suitable brackets of the casing 175. The bearings are fed by condensed motive fluid returning from the condenser through ducts 177, 178. This embodiment is basically the same as the former embodiment of the unit illustrated in FIG. 5.

In accordance with FIG. 10 shaft 182 of turbine 180 and generator 181 comprises an axial bore 185 communicating with bearings 183, 184 by means of lateral bores 186, 187. Bore 185 is fed with returning liquid motive fluid through duct 188.

The embodiment according to FIG. 11 is basically similar to that of FIG. 9. In this case shaft 192 comprises two terminal axial bores 195, 196 merging respectively into lateral bores 197, 198. Bearings 193, 194 comprise axial bores 190, 191 aligned, respectively, with bores 195, 196 and the lubricating liquid is supplied through ducts 200, 201.

In the embodiment according to FIG. 12, one of the shafts 212 that is journaled in a bearing 211 comprises an axial bore 215 and lateral bores 214. This bearing is fed with lubricating liquid running through duct 219. The second bearing 213 communicates with the first through a U-shaped duct 217 through which it receives its supply of lubricating liquid.

In the embodiment according to FIG. 13, the shaft 220 is static and forms part of the casing. Against this, bearing 221, 222 form part of the rotor block 223. Shaft 220 comprises an axial bore 224 and communicates with the bearings through bores 225, 226. The supply of lubricating liquid is through duct 227.

It is seen from the preceding description that in all the self-starting power generating units according to the invention, whether of the pump-fed or gravity type, auto-lubrication is automatically ensured once the boiler heat is turned on, and is maintained after the boiler heat has been turned off for as long as the turbine keeps revolving. This means in other words that in order to start or turn off a power generating unit according to the invention all that is necessary is the turning on or off of the heat supply. No further manipulations are required for ensuring lubrication and this constitutes a substantial departure from and considerable advantage over the prior art.

We claim:

1. In a self-starting power generating unit operating with a volatilizable motive fluid in a closed Rankine cycle system and comprising as components a boiler for the evaporation of the liquid motive fluid to a vapor, means for heating the boiler, a turbine having nozzles fed with the vapor from the boiler, a condenser for condensing the exhaust vapor from the turbine to a liquid fluid, and means including a return line returning said exhaust vapor liquid fluid from the condenser to the boiler, some of the components including revolving parts mounted on bearings requiring lubrication: that improvement comprising locating the bearings to be lubricated in said return line and, having at least one of said turbine nozzles arranged for a continuous supply of vapor to the turbine from the boiler during the start-up and slow-down of the unit when the pressure in the unit is below the design value.

2. A self-starting power generating unit according to claim 1 having the condenser mounted above the turbine, characterized in that the unit further includes a vessel inside the condenser adapted to collect the condensed motive fluid, and in that ducting means is provided for conducting liquid motive fluid by gravity from said vessel into the bearings.

3. A self-starting power generating unit according to claim 1 of the pump fed type, characterized in that an auxiliary turbine wheel is located in the path of the vaporized motive fluid which turbine wheel is arranged to be operated by the vaporized motive fluid and which auxiliary turbine wheel powers accessory apparatus.

4. A self-starting power generating unit according to claim 3, characterized in that said auxiliary turbine wheel is located in the path of the exhaust vapors from the turbine to the condenser.

5. A self-starting power generating unit according to claim 3, characterized in that said auxiliary turbine wheel is located in the path of the vapor from the boiler to the turbine.

6. A self-starting power generating unit according to claim 3 of the pump-fed type, characterized in that said auxiliary turbine wheel is adapted to operate the pump for the motive fluid.

7. A power generating unit according to claim 6, characterized in that the condenser is cooled by a liquid coolant and the pump for the liquid coolant is magnetically coupled with the pump for the motive fluid.

8. A self-starting power generating unit according to claim 6, wherein the condenser is air cooled, characterized in that the condenser is fitted with a fan magnetically coupled with the pump for the motive fluid.

9. A power generating unit according to claim 1, characterized in that a heat storage element is provided inside the boiler and the condenser for prolonging vapor formation during the slow-down phase.

10. A power generating unit according to claim 1, characterized in that means is provided for reducing the
rate of cooling of the condenser, which means is coupled with the means for controlling the heating of the boiler, so that when the boiler heat is turned off the condenser efficiency is reduced whereby the exhaust pressure is increased.

13. A power generating unit according to claim 11, characterized in that there is provided a butterfly valve mounted between the turbine and condenser, which valve is coupled with the means for controlling the heating of the boiler so that when the boiler heat is turned off the butterfly valve is shut whereby the exhaust pressure is increased.

14. A power generating unit according to claim 11, characterized in that there is provided a switch-controlled resistance connected across the terminals of the generator, which switch is coupled with the means for controlling the heating of the boiler, so that when the boiler heat is turned off the resistance circuit is closed whereby the load on the generator is increased and the generator is braked.

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